CROWD SOURCED FORMAL VERIFICATION – AUGMENTATION (CSFV-A)

CHARLES RIVER ANALYTICS, INC.

JUNE 2016

FINAL TECHNICAL REPORT

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14. ABSTRACT

Formal verification (FV) ensures that mission-essential software is free from disruptive errors and security vulnerabilities, but requires human experts that can be quickly overwhelmed by the increasing number, size, and complexity of software systems. DARPA's Crowd Sourced Formal Verification (CSFV) program built games that recast FV problems into puzzles to make these problems more accessible, increasing the manpower to construct FV proofs. This effort supported the CSFV program by hosting the games on a public website, and analyzed the gameplay for efficiency to provide FV proofs.

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1. SUMMARY

Formal Verification (FV) ensures that mission-essential software is free from disruptive errors and security vulnerabilities, but requires human experts that can be quickly overwhelmed by the increasing number, size, and complexity of software systems. The Defense Advanced Research Project Agency (DARPA) Crowd Sourced Formal Verification (CSFV) program has been building games that recast FV problems into puzzles to make these problems more accessible, increasing the manpower to construct FV proofs. Much progress has been made in the CSFV program to date; however, it has become clear that it's a struggle to make engaging games that foster human participation and effectively address formal verification problems. To augment this work—and complete the evaluation of a game-based approach—DARPA needed a team to maintain and extend the CSFV website, perform additional game analytics, and investigate alternative incentive methods to assess other approaches to crowd sourced software verification. To address this need, we conducted a CSFV augmentation effort (CSFV-A), in which we:

- Managed the Verigames website and integration framework through the close of the program, updating that website to incorporate Phase 2 games and enabling the evaluation of this new game set as a tool to reduce the cost of formal verification
- Managed collaboration activities across the CSFV program (including cross-team integration meetings)
- Expanded our analytics efforts for CSFV; in addition to expert game design analysis and user studies, we analyzed the play styles and motivations of game experts (*gurus*) using cognitive systems engineering (CSE) techniques
- Assessed pay-for-play and other incentive mechanisms for CSFV, evaluating their effectiveness and cost in comparison to standard formal verification approaches
- Marketed the CSFV games to engage participants in the crowd sourcing efforts
- Managed the overall program to provide high quality, on-time deliverables

Our integration effort under CSFV developed key infrastructure software to address Technical Area 2 (TA2) game integration needs, provided technical insights into game improvements, investigated the impact of payment approaches compared to altruism and game-based incentives, provided feedback using expert game design and user analysis to improve the playability and engagement value of the games, provided an approach to generate automation and training to improve CSFV performance based on expert game player analysis, and discovered that paid crowd sourcing methods perform more effectively than the current game-based approach.

2.   INTRODUCTION

2.1   Problem Description

Formal Verification (FV) ensures that mission-essential software is free from disruptive errors and security vulnerabilities, but requires human experts that can be quickly overwhelmed by the increasing number, size, and complexity of software systems. DARPA's Crowd Sourced Formal Verification (CSFV) program has been building games that recast FV problems into puzzles to make these problems more accessible, increasing the manpower to construct FV proofs. To date, in the CSFV program, much progress has been made—however, it has become clear that it's a struggle to simultaneously make engaging games that foster human participation, and can effectively address formal verification problems. To augment this work—and complete the evaluation of a game-based approach—DARPA needed a team to maintain and extend the CSFV website, perform additional game analytics, and investigate alternative incentive methods to assess other approaches to crowd sourced software verification.

2.2   Technical Approach

We conducted a CSFV augmentation effort (CSFV-A) that addressed these needs. We successfully managed the Verigames website and integration framework through the close of the program. Verigames.com was a single entry point to access all CSFV games developed under the DARPA program. Through the CSFV program we updated that website to incorporate Phase 2 games, enabling the evaluation of a new game set that is designed for better engagement. We worked with Appirio's TopCoder service to address extension and maintenance requirements, using the same contest-based approach to development used in previous CSFV work. Through these efforts we successfully exploited the crowd resources that were already familiar with Verigames.

To evaluate these games, we expanded our analytics efforts for CSFV. We continued our focus on expert game designer analysis and user studies to review the games and provide feedback for improvements, and used computational analytics to assess game play characteristics and marketing performance. We performed an innovative analysis of expert player approaches to the game and expert player motivations, using cognitive systems engineering (CSE) techniques to observe and document the game play of the most significant contributors (*gurus*) that were available from each game (unfortunately, many of the gurus were not available for these events).

We explored and assessed alternative incentive mechanisms for CSFV. In previous CSFV work by Technical Area 1 (TA1) teams, the focus was on a combination of altruism and engagement value, designing game-based mechanisms that attract citizen scientists wishing to contribute to formal verification proofs. In Phase 2, we enabled a pay-to-play mechanism to address CSFV needs, testing the ability for limited payments in traditional crowd sourcing environments to encourage greater participation and contributions to CSFV (via Amazon's Mechanical Turk). We also explored a contest-oriented incentive mechanism in which players who perform particularly strongly in the games (produce the highest scores) gained access to extra community events and acknowledgement on the website. Finally, we investigated the use of TopCoder Bug Hunts as a means to drive more game play traffic on the website as another pay-to-play incentive approach. Each of the pay-to-play mechanisms explored had significant impacts on play characteristics and timeline, and were ultimately successful tools to enhance crowdsourcing contributions. The contest-oriented incentives did not have a significant impact

on participation; however, that may be because we were not able to provide payment-based incentives in that effort.

We made a few changes to this technical approach during the effort. We changed the contest from a monetary-based reward to a non-monetary, community-based reward to make the contest feasible to execute, while maintaining the potential for increased play statistics. We also identified the need to maintain a basic Verigames website beyond the end of the program, so we designed and generated a basic website that does not host the games, but rather points to games hosted by the TA1 teams.

2.3 Technical Objectives

Under this effort, Charles River Analytics executed a Crowd Sourced Formal Verification (CSFV) augmentation effort. Our first objective was to manage the Verigames website and integration framework through the close of the program, updating the site to incorporate Phase 2 games, and enabling the evaluation of this new game set as a tool to reduce the cost of formal verification. To evaluate these games, our next objective was to continue and expand our analytics efforts for CSFV. In addition to expert game design analysis, user studies, and computational analytics, we analyzed the play styles of game experts (*guru's*) using cognitive systems engineering (CSE) techniques to observe and document their approaches. Next, we assessed pay-for-play incentive mechanisms for CSFV, evaluating their effectiveness and cost in comparison to standard formal verification approaches. Specifically, we explored using Mechanical Turk to motivate accomplishment, and contests to motivate participation in the game-based approach. We also maintained targeted marketing efforts to foster crowd participation in CSFV.

The purpose of the DARPA CSFV program is to investigate low-cost alternatives to software verification that can reduce the reliance on expensive expert computer scientists and mathematicians. The CSFV-Augmentation (CSFV-A) effort (Phase 2) supported this objective in the following ways:

- *Provide a robust and attractive web-based delivery platform for game-based formal verification tools*. We updated the Verigames website to incorporate the Phase 2 games being developed by TA1 performers, and provided those games in a robust and attractive format to engender crowd participation.
- *Explore game analytic methods to enhance crowd participation in gameplay*. We used expert analysis, computational analysis, and user evaluation to make recommendations to TA1 performers to improve the playability of the games. Phase 2 also included an evaluation of experts' (*gurus*) play styles to recommend improvements to tutorials to generate more experts, and potential approaches to develop automated agents that mimic those play styles.
- *Explore contests to enhance crowd participation in game play*. We explored the use of contests to drive increased participation in game play. Specifically, a single contest was held, with manageable prizes, and data was collected on the impact this contest has on player participation.
- *Assess paid crowd sourcing as a low-cost alternative to expert formal verification*. We developed an integration platform for TA1 performers with Amazon's Mechanical Turk (AMT). Charles River Analytics worked with TA1 performers to integrate non-game tasks into AMT, and tested the ability for minimal payments to produce useful inputs to formal verification proofs.
- *Market key CSFV efforts*. During Phase 2, Charles River Analytics worked with GameDocs to market Phase 2 game releases, Phase 2 game contests, and paid crowd sourcing releases to drive increased crowd participation in the CSFV effort.

3.   METHODS, ASSUMPTIONS AND PROCEDURES

3.1   Presentations

We presented a paper with Dr. Drew Dean at the 2015 USENIX Summit on Gaming, Games, and Gamification in Security Education (3GSE '15) on August 11, 2015.

3.2   System Architecture

The primary focus of our effort was to update, maintain, and host the Verigames website and integration framework to enable continued testing of Phase 2 games. The Verigames website architecture features separate content, personalization, persistence, and game support tiers that are loosely connected by a RESTful API. This architecture allows for the development, maintenance, and hosting of several games developed in different technologies and for different purposes. Each Verigames Site game may operate singly, and to integrate with the whole, can asynchronously call the API to authenticate users, record scores, record game statistics, or pull user profiles. Figure 1 illustrates the architecture of the Verigames website.
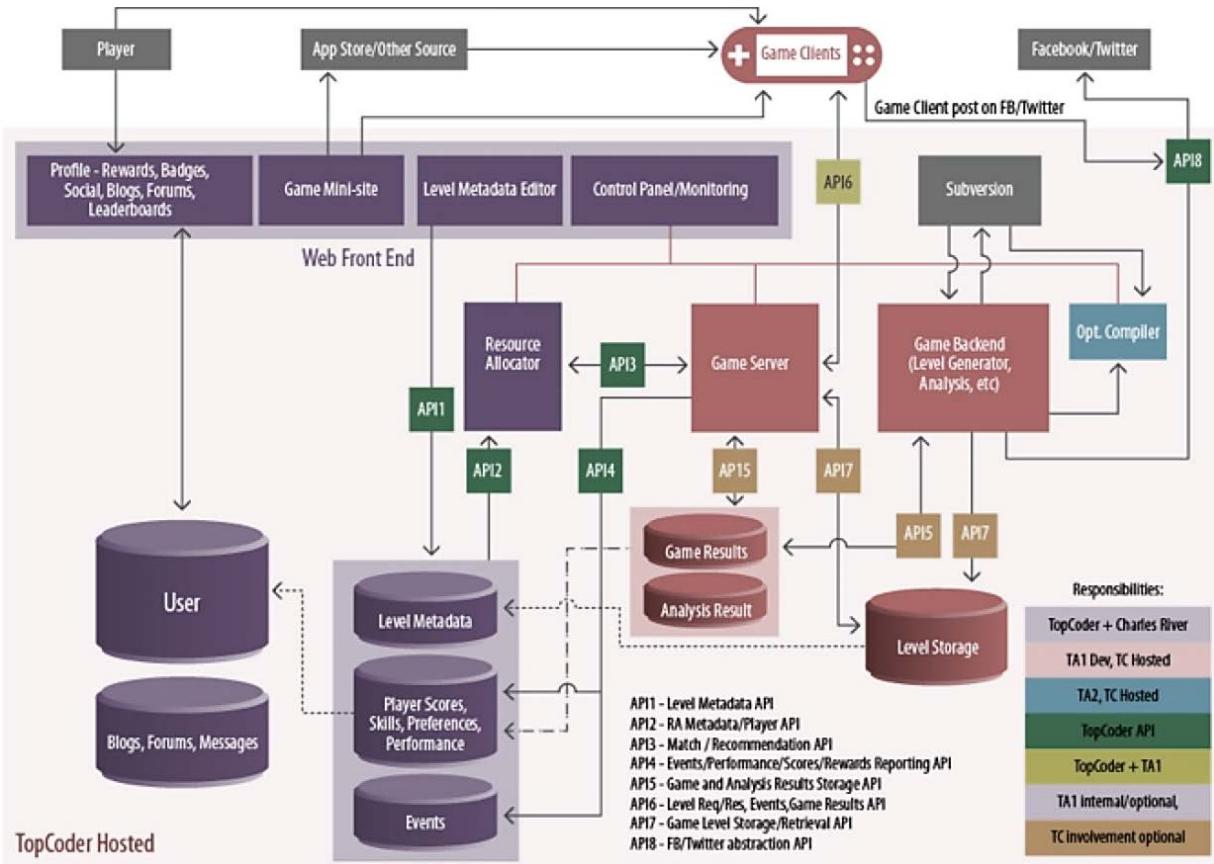
Figure 1 Verigames Website Logical Architecture

The Verigames.com infrastructure operates on the Amazon Web Service (AWS) platform. AWS is a class of managed services offered by Amazon. By using the AWS cloud, the Verigames system benefits from the 99.999% uptime that Amazon provides. The Verigames

system also benefits from virtual machines (VMs) offered at significantly lower cost than dedicated hardware and from managing resource allocation and CPU configuration and count via web services and management dashboards. This approach offered maximum flexibility and reliability at minimum cost. Figure 2 illustrates the Verigames.com AWS architecture.
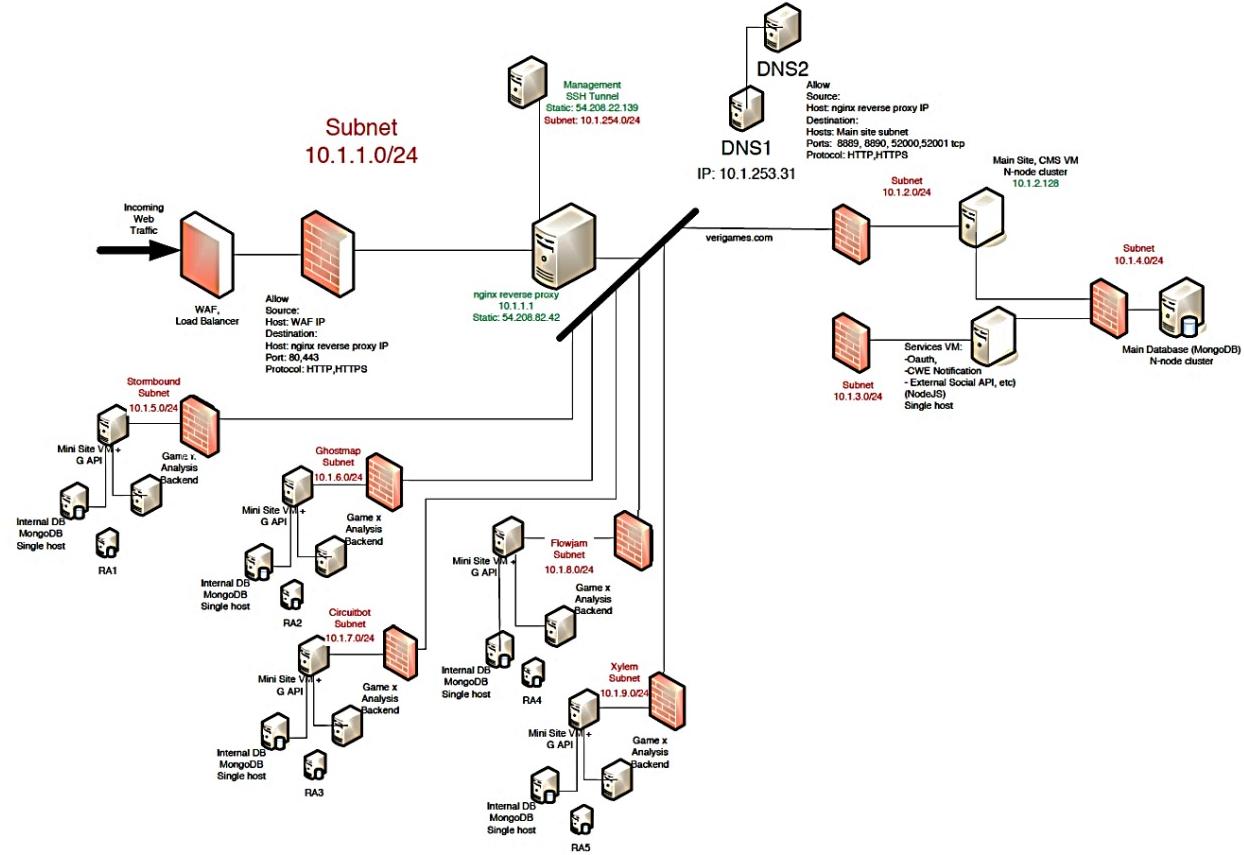
Figure 2 Verigames.com AWS Architecture

The program established three environments using AWS cloud technology:

- Production environment for hosting the public site (Verigames.com)
- Testing environment (Verigames.org) for staging the site for testing before updates are posted to production
- TA1 development environment that allocates VMs on AWS for specific game developers

In the production environment, the system is configured as follows:

- Six large VMs, one for each website
- Nginx hosted on a dedicated small VM
- logaholic hosted on a dedicated small VM
- mysql hosted on a large VM
- Five medium VMs, one for each team's backend and verification
- Amazon S3 for storing photos and uploaded files/attachments in the websites and Amazon SES for sending emails

In the stage/testing environment, the system is configured as follows:

- Six large VMs, one for each website
- Nginx hosted on a dedicated small VM
- Medium VM for Mechanical Turk dashboard
- Two extra-large VMs to create install DVDs
- Ten small VMs, two for each team's backend and verification
  Ten micro and small VMs were allocated to individual TA1 and game developers.

3.3 Update, Maintain, and Host Website and Framework

We maintained the Verigames websites for the CSFV augmentation program to support continued analysis of game-based crowd sourcing. We analyzed and optimized the efficiency of the website, strategically addressing issues to ensure that download times did not prevent a successful CSFV experience for users. Charles River Analytics performed this analysis and improvement during the deployment cycle, augmented by TopCoder QA contests. We also worked with WhiteHat Securities to assess security issues on the new Phase 2 game pages, addressing security issues as they were identified.

3.3.1 Website Improvements

The Verigames website was updated to address issues identified in integrating TA1 Phase 2 games, enhance usability, and to incorporate additional pages to:

- Market to citizen scientists to foster more effective community support for the scientific objectives of CSFV
- Track high scores and awards to support a performance-based contest
- Better manage the website

We also integrated the Mechanical Turk platform and implemented tags for contest winners after the high scorer contest.

The Citizen Science page portrays materials in a manner that attracts citizen scientists, with a focus on the science and advancement generated by the community (as opposed to a game-centric approach). We believed this approach would be more attractive for common community members participating in CSFV. Our initial citizen science page was made available as a secured page (via link) on May 6, 2015.

Specifically, we ensured all the content on the verigames.com site was up to date and relevant to Phase 2. We converted existing 2014 videos into Phase 2 content (e.g., referring to Phase 2 games). We also considered podcasts, articles, and blog posts for previously generated but unused content.

We compiled all relevant scientific information for the Citizen Science page and provided content and instructions for adding and formatting the content. We added sharing icons to the Citizen Science page and a Play Now call to action. We integrated science links on the play pages that display the Citizen Science page. We updated the Citizen Science page throughout the effort with new media articles, blog posts, and videos, as well as scholarly articles, and we added a feed from the Monster Proof game with analyzed lines of code. We rewrote the About Us section of the website to improve the PR story and provide additional information for press outlets. We added content to the News page and Forum to promote community events, press events, and new site content and frequently updated the drop-down banner to promote community events and contests. We also changed the layout of the home page to better showcase

its content and we added new content to show the results of games that provided live statistics on formal verification results.

Once changes were implemented, we reviewed the website and entered Jira tickets to correct errors and bugs, and we monitored the Forum and email for customer support queries.

3.3.2 Friends & Family Release

We began our effort by updating and creating virtual machines on the production server for each of the Phase 2 games, accessible via non-indexed web addresses. We fixed issues as they arose to allow the games to be hosted on directly linked sites for the Friends & Family Beta test. See Appendix A for a summary of technical accomplishments in support of this release.

We gathered lists of usernames from each of the TA1 teams to be invited to participate in the Friends & Family Beta test and added the stored email addresses for those names to lists in MailChimp, so that user information would remain blind to the TA1 teams. We sent emails for the event that included art and a description of each game.

We were prepared for the Friends & Family Beta release on March 31, 2015 for four of the five TA1 teams, but were delayed due to the need to approve game materials for public release. We coordinated the submission of assets, text, and audio materials from the games to DARPA for approval. Once they were approved, we waited until April 7, 2015 for the fifth game to be ready. The Friends & Family release went live with four of the five games on April 8, 2015 (Dynamakr, Ghost Map: Hyperspace, Monsterproof, and Paradox), with the fifth game released on April 10, 2015 (Binary Fission).

3.3.3 Website Security Test

We had an early version of the public release in place for April 31, 2015 to run the WhiteHat test for website security. Our WhiteHat evaluation identified minor issues unlikely to cause security leaks. We decided not to address these issues, as the risk was low compared to the expense for a resolution.

Specifically, WhiteHat identified a single (albeit repeated) issue for Verigames security—specifically, an *Insufficient Transport Layer Protection* fault. Several pages used transport layer protection (HTTPS), but loaded content that did not use transport layer protection (HTTP). Insufficient transport layer protection allows communication to be exposed to untrusted third parties, providing an attack vector to compromise a web application and/or steal sensitive information. When the transport layer is not encrypted, all communication between the website and the client is sent in clear text, which leaves it open to interception, injection, and redirection, also known as a man-in-the-middle/MITM attack. An attacker may passively intercept the communication, giving them access to any sensitive data that is being transmitted, such as usernames and passwords. An attacker may also actively inject/remove content from the communication, allowing the attacker to forge and omit information, inject malicious scripting, or cause the client to access remote, untrusted content. An attacker may also redirect the communication so that the website and client are no longer communicating with each other, but instead are unknowingly communicating with the attacker in the context of the other trusted party.

The pages identified as vulnerable contained resources categorized as passive mixed content that were displayed to the user and had minimal impact on the behavior of the page. These

include audio files, images, videos, and other objects. This issue was not exploited by third parties and caused no problems on the website.

3.3.4 Official Public Release

All Phase 2 games were ready for play by the public on May 27, 2015. The verigames.com website was ready, including logins, forums, and links to the new games. The official public release supported contests and observations that occurred later in the effort.

3.3.5 Play Statistics

We tracked play statistics for registered and anonymous users throughout the period, as shown in Figure 3 and Figure 4.
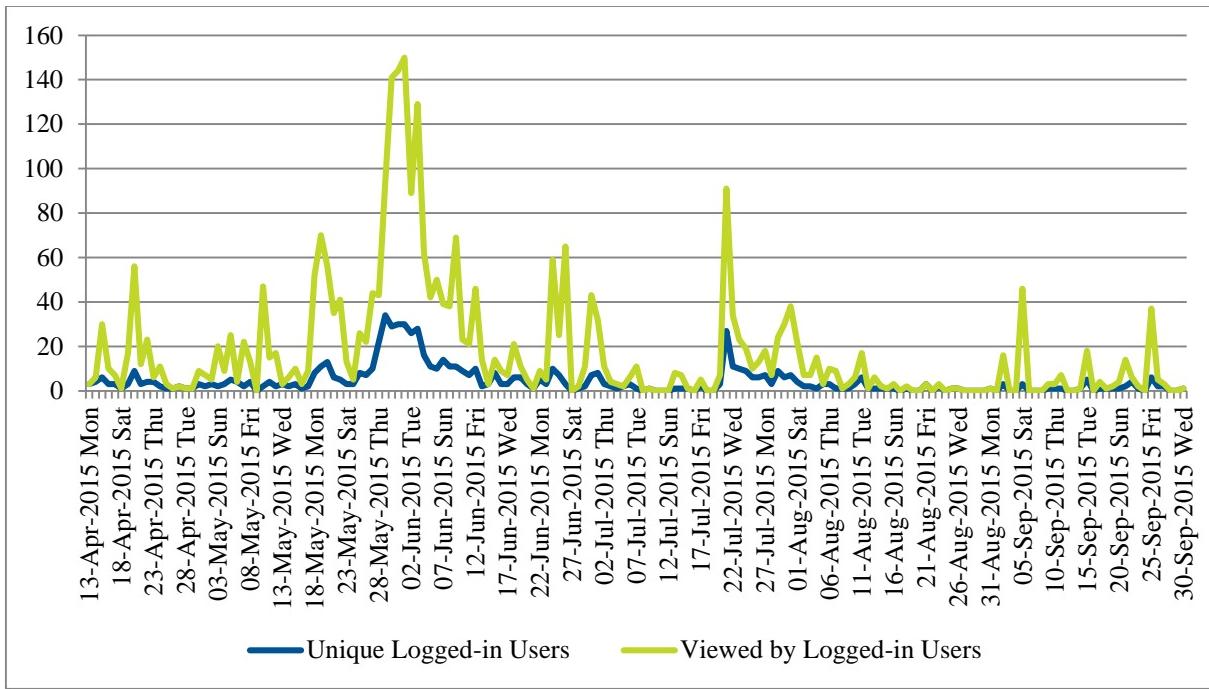
Figure 3 Statistics for Registered Verigames Users
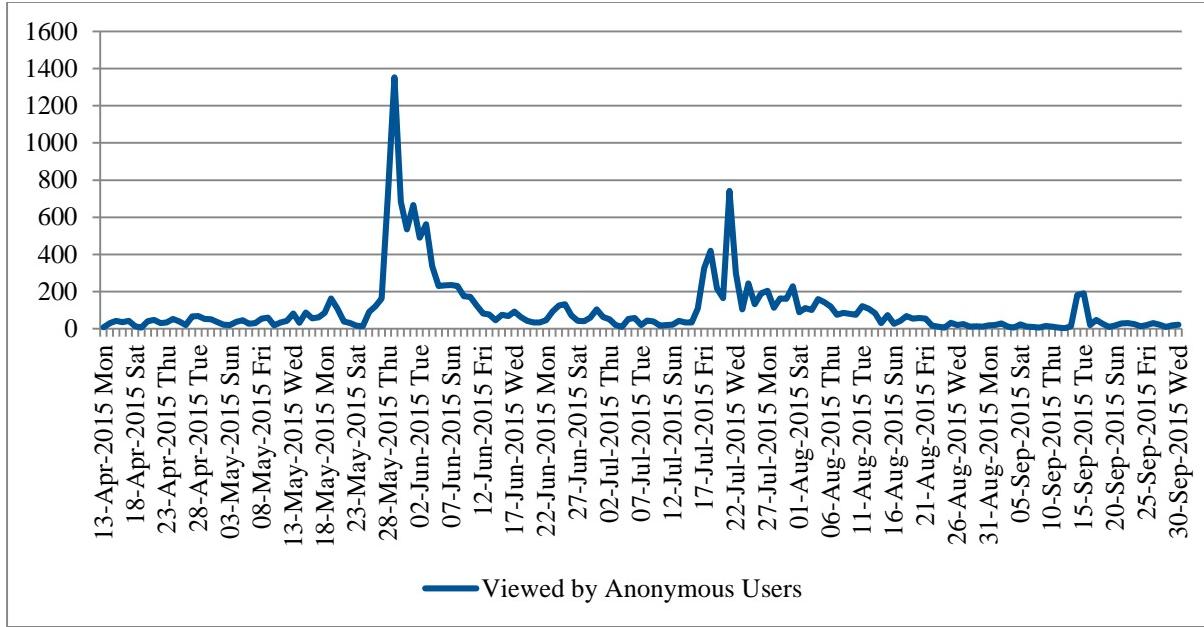
Figure 4 Statistics for Anonymous Verigames Users

A significant spike occurred at the end of May, when the Phase 2 games went live with the public release and a DARPA news item. Smaller spikes were associated with our marketing efforts, such as the spike around June 25 due to marketing the beginning of the guru search, but the traffic was low in comparison to our original participation spike. We explored methods for improving participation with our marketing consultants, GameDocs, as described in Section 3.7.

In July, spikes occurred due to the BBC and other press releases, and the beginning of the Verigames contest. In August and September, traffic lowered as the marketing effort ended, with some spikes due to the TopCoder Bug Hunting events. The remainder of the program had numbers similar to those seen in late August and September, as there are currently no planned marketing events to increase numbers. Numbers after September were quite low in comparison; we expect that his was primarily because we ended the marketing effort in September.

3.3.6 Permanent Website

We closed the staging and productions servers at the end of November 2015 and created a limited website for permanent hosting that provides links to the permanent BBN, Washington, and SRI game sites. The primary intent of this website is to ensure that publications always point to something associated with Verigames.

3.4   Manage Program Collaboration

We maintained and managed existing collaboration efforts for CSFV throughout the effort. We maintained BaseCamp as a collaboration environment for planning and engineering discussions, and Jira for reporting potential issues with the website and integration framework.

We held weekly meetings with each TA1 team to identify each team's specific requirements for the website and integration framework. We held biweekly cross-team meetings with Charles River, Appirio, and TopCoder to discuss integration needs, including Verigames and Mechanical Turk integration. We held game design meetings to discuss expert analysis, status of the games,

and refinements to the games to improve their playability. We held weekly marketing meetings with GameDocs to track CSFV marketing efforts and guide TA1 teams in their marketing efforts.

3.5   Analyze CSFV Games

A key facet of our effort was continued analytics to help improve the games and marketing efforts. To date, our most successful analytics involved using game design experts to review, in detail, the game environment, gameplay mechanics, and surrounding narrative and content. We continued to perform this task through the close of game development efforts, holding biweekly meetings with the TA1 performers to discuss game design topics that can drive game improvements. Expert-based analysis offers many advantages, producing straightforward, actionable recommendations without the need for large player communities, and allowing analysis of factors that cannot be considered based on pure data.

To better understand how games might be improved, we invited the top contributors (known as *gurus*) for each of the Phase 1 games to the Friends & Family Beta release of the Phase 2 games, providing an early opportunity for these individuals to become guru's in the new game setting. We then invited the best performing experts to in-person interview and observation sessions with DARPA and CSFV personnel to analyze their play style and approach. Top performers were invited to our facility, specifically designed for usability observation, where we observed and recorded their game play and asked targeted questions to understand how they addressed the problems in these games. A cognitive systems engineering (CSE) approach (Roth & Bisantz, 2013; Roth et al., 2010) guided this effort with best practices for evaluating expert behaviors. When performing this analysis, our primary objective was to identify play style elements that can potentially guide the development of automated agents to play the games and further improve the efficiency of formal verification. A secondary objective was to use these play style elements to guide the development of training materials to generate higher performing users across the community. Both of these objectives can greatly enhance the contributions of crowd sourcing to formal verification processes. We held this event in concert with the PI meeting in June, inviting the top contributors to that meeting for a parallel analysis.

To improve user attraction and retention on verigames.com, we conducted a round of usability testing on the Phase 2 games. This was a web-based usability testing session scheduled to align with the Friends & Family Beta release, where the focus was to get rapid recommendations for improvements to implement for the full release. YouEye performed this task.

We pursued computational analytics where possible, given the data made available by the TA1 performers and the marketing team. Metrics-based analytics focused on the measurable aspects of the play experience at different scales—from individual levels to play sessions to careers—and largely sought to find common aspects of "successful" and "unsuccessful" play patterns across the spectrum of factors. These factors included marketing efforts, as well as tutorial experience, level design and features, sequence of level distribution, strings of successes or failures, and meta-game factors.

3.5.1 Expert Analysis

We conducted an expert analysis of the five Phase 2 games (Dynamakr, Binary Fission, Monsterproof, Paradox, and GhostMap: Hyperspace). The full reports are included in Appendices B through F.

Based on this analysis, we determined that two of the games needed to refine their terminology and the order in which they presented concepts to the player to make sure that players understand what they are supposed to do and what to expect from their actions. All the games needed to refine their reward loops to ensure players gain some personal value from play past the tutorial. These and other recommendations to improve the games were addressed by many of the TA1 teams before the official public release.

3.5.2 Usability Study

We worked with YouEye to execute a usability study on the five Phase 2 games. More detailed reports are provided in Appendices I through M. Full-scope video results are available online. The level of detail for each analysis was driven by the level of interaction from the TA1 teams (that is, TA1 teams that used the service and requested analyses received more detailed feedback).

Table 1 provides a summary of the key findings of the usability study.

Table 1 YouEye Key Findings for Phase 2 Games

Game	Key Findings
Dynamakr	1. Initial intro and design allures people to potential of engaging gameplay. Maintain sound effects and galactic scale. 2. High success with building patterns, some players missed the energy building requirement. 3. What makes a pattern better than others? Why would you load up on the right, but not the left? 4. Unless paying close attention it is very easy to miss how pattern building relates to what the Dynamo experience will be. This is *pivotal* to the game. Should players be utilizing strategy when building patterns as a way to impact the Dynamo shootout? If so, communicate this earlier. 5. Make certain that Go Dynamo! and Continue buttons are large and noticeable, some players missed them initially which caused delays. Potentially, remove the need to click to the next space, as long as there is some transition demo to introduce the Dynamo and its levels 6. The majority of players suggested leveraging more tooltips and hover instructions when doing certain interactions, rather than large chunk of text before and after parts of tutorial.
Monster Proof	1. The difference between the first proof and later equations scales rapidly with little opportunity for confidence building. 2. Tutorials require too much time – requires a lot of memory retention. 3. It is very important to give feedback when proper balance of monsters is initiated. Don't wait for the player to test the equation. 4. The map felt too rigid for some players, but the collection of tools and early challenges excited many. 5. Tutorials escalate in difficulty too quickly. Use easy levels over and over to build confidence, gain some tools, and introduce the other game mechanics so players don't lose faith.

Game	Key Findings
Ghost Map: Hyperspace	1. Introductory voiceover should contain a video of some sort to excite and engage players. The voiceover is easy to click through and miss. 2. Greatest confusion is around Rift Sealing. Why must they use the bottom right sliders rather than interacting in the primary map area? 3. Participants did not seem to grasp the connection between Combat and Rift Sealing. How does a good seal relate to killing the bugs and locking? 4. Locking a map in and of itself is not made entirely clear. Players achieved this, but is it just to keep the map clean? Or does it have a larger purpose? 5. Feedback for bug health, along with health vials on the left side of the game, did not have clear enough feedback/values.
Paradox	1. Tutorial instructions too distant from paintbrush actions and paintbrush type; it was difficult for players to recall the strengths of paintbrushes. 2. When new paintbrushes are introduced, animation demo of how they differ would be helpful, as would the ability to constantly be reminded via hover or by including the name of brush next to the brush image. 3. The design palette is slightly soothing and a bit polarizing; it was too dull for some players. But for several players, it achieved a nice tone. 4. Scale and scope of map size is still a bit jarring when later levels are played. Playing a map incrementally, starting from further zoomed in on the difficult areas, may lead to a better engagement curve.
Binary Fission	1. Simplicity of the game leads to fairly successful ramp-up, but a video demonstration or light back-story would increase engagement. 2. Minimal feedback during filter splitting leads to doubt; utilize sound or color feedback to increase awareness of success or failure 3. Once the levels get tough, understanding the mechanics builds confidence, but ~50% of the participants wanted something more to work towards. Some assumed that the correct filter path created a larger pattern or form, but this was not ever confirmed. 4. Design mostly pleases. Largest gap in elements is how score is calculated. 5. Increase the competitive nature through friend referral and 1-on-1 competition of the same levels. 6. Most participants could have used a slightly longer transition to harder levels while mechanics are given feedback and the score is explained.

The independent user feedback provided in these studies helped the TA1 teams further improve their games.

3.5.3 Computational Analysis

We conducted a computational analysis of gameplay for the Phase 2 games to better understand the statistics surrounding player attrition and marketing efforts. We developed a basic framework for cleaning the data files provided by TA1 teams (e.g., removing testing instances; removing overly long play sessions; determining the number of sessions played; determining play time; determining if the player is new or retained), and performing basic clustering, graphing, and statistical analyses on that data.

To determine which game features lead to increased or reduced retention and/or productivity, we used statistical techniques to analyze the relationships between game characteristics and game play for the games that provided significant data sets (Monster Proof, Dynamkr, and Paradox). For Monster Proof, there was a clear performance and retention difference between players using tools, and those not using tools; players who did not use tools tended to struggle with the game, quit levels, and ultimately leave. For Dynamakr, players were likely to leave if they got an initial level that was too difficult. For Paradox, players who used the optimizer were more successful and more likely to be retained. Table 2 provides more details on these results.

Table 2 Statistical Analysis Conclusions for Monster Proof, Dynamakr, and Paradox

Game	Statistical Analysis Conclusions
Monster Proof	▪ Players do not seem to be making good use of the tools provided (e.g., infrequent use of free actions, downward trend in using new tools). ▪ Tools are generally used more when they are first introduced (e.g., mandated by the training tools). ▪ Players are generally not improving in the levels completed per session, implying that this is not a choice made for efficiency.
Dynamakr	▪ Attrition is more likely on low difficulty and/or lower impact levels. ▪ Attrition is more likely when player performance is low. ▪ Attrition increases significantly when play count surpasses 50. This implies that we may want to introduce rewards at regular intervals to overcome these attrition issues.
Paradox	▪ Retained players tend to use the optimizer a lot more than those leaving the game; it seems that the more players learn to use the optimizer, the more likely they are to keep playing. ▪ Optimizer use also results in higher scores in general.

3.5.4 Guru Knowledge Elicitation

Working with SRI and BBN, we participated and helped to manage two Guru events. The first was held on August 20, 2015, and the second was held on September 24, 2015. Players were gurus in *Ghost Map: Hyperspace and Binary Fission*.

We discussed the games extensively with the guru's, and received feedback to guide future development efforts. Some specific feedback included:

- There should have been a larger focus on community. For any sort of public game, it is essential to set up a thriving community that encourages collaboration, socialization, and discussion. The community forums on Verigames did not effectively achieve that for a number of reasons, such as ease of use, unclear links and proximity to actual games, lack of community moderation. The *Binary Fission* chat feature did a better job; something like that would have been great in all of the games.

- We should have exploited streaming from game players. Our gurus tended to stream their gameplay. We could have taken advantage of that, and linked those streams on the Verigames website or forum to show other players how to play effectively.

- There was a strong interest in active participation in beta testing. A lot of early adopters are very interested in helping in the debugging process. Embracing that level of feedback is essential to testing and improving the game system.

The guru's provided a deep evaluation of the latest update to BBN's *Hyperspace* game. In addition, they gave an initial evaluation of *Dynamakr*, *Binary Fission*, and *Paradox*, providing generally useful feedback for each of those games. More time was spent on *Dynamakr* and *Binary Fission*, in particular, as the developers for those games participated via web conference. BBN recorded a video of the guru's *Paradox* play, and provided this video to University of Washington to provide them feedback for moving forward.

Concluding our guru-based analysis, we found that gurus provide useful feedback for improving the games and addressing potential game issues. Both of our gurus focused on *Hyperspace*. For those games, our gurus tended to achieve success primarily because they enjoyed the game enough to continue playing at a rate that contributed useful formal verification content. They were not able to discern any specific strategies that seemed conducive to game success (indeed, in some cases, they actually were using strategies that did not benefit them in

any way whatsoever). When observing their game play, we did not discern useful strategies for training or automation purposes. While it may be the case that gurus for other games may have provided more clear benefits, because they did not participate in guru events, we were unable to interview them.

However, gurus did identify issues in existing training materials (e.g., points where the training materials were confusing or misleading), and identified game issues and bugs. We observed that direct discussion between the developers and the guru provided both parties with great insights into the game, allowing developers to improve their game mechanics and objectives, and gurus to improve their approach to playing the game. We would certainly recommend that future efforts maintain an active community interaction between developers and game players within a beta-test format, allowing game players to interact directly with developers to provide feedback and discuss issues. We expect that this strategy will both identify problems in the game and lead to critical insights into the ways that players approach these games. These insights will lead to the design of better tutorials, better game mechanics, and ultimately better citizen science tools.

3.5.5 WebEx Event for Contest Winners

We held the WebEx event with contest winners in October, and explored questions of game strategy with them. As we anticipated, our results were similar to other games—that is, the players had more success through brute force than through any discernable strategy that could be taught or automated.

3.6 Develop, Manage, and Assess Alternative Crowd Sourcing Incentives

To explore the success of other incentive methods for crowd sourced formal verification, we assessed pay-for-play programs. In particular, our objective was to compare the cost of contributions from pay-for-play methods compared to the costs of similar contributions from pure game-based approaches and from current standard methods (e.g., formal verification companies). Specifically, we explored two pay-for-play systems. Amazon's Mechanical Turk, a payment-based crowd sourcing mechanism, and TopCoder Bug Hunts, in which TopCoder community members were paid to find bugs in active game levels for each game. We also held a contest in which the best performers (i.e., highest US citizen scorer at each game) were to be hired as paid subject matter experts to provide insights into game improvements.

3.6.1 Crowdsourced Formal Verification Using Amazon's Mechanical Turk

Amazon's Mechanical Turk is a payment-based crowd sourcing mechanism. Mechanical Turk organizes tasks into Human Intelligence Tasks (HITs) that are posted to the work page and performed by users. We organized HITs into levels for a specific game, and they were addressed on a first-come, first-served basis. The system was organized with the following assumptions:

- TA1 games were reskinned to limit play to specific levels
- The reskinned levels had the same progression as the games
- HITs were collections of some number of levels with similar skill requirements
- TA1s assigned levels to specific HITs
- HITs associated with game levels that are more difficult to play were assigned higher prize values than HITs associated with game levels that are easier to play

TopCoder designed and implemented a system for posting HITs to Mechanical Turk and synchronizing task completion with Verigames.com. In this system:

- Unique username and password combinations were created on verigames.com
- Combinations were assigned to each HIT
- Upon first time use of a combination, the user was required to change the password, thereby personalizing the associated HIT and preventing other users from executing the same task
- The AMT API was used to synchronize data between Verigames.com and AMT
- We budgeted pay-for-play awards beginning in June 2015 and ending in August 2015

We implemented the APIs for supporting Mechanical Turk integration using Appirio's TopCoder service for the three TA1 teams that participated in the paid crowd sourcing evaluation (Dynamkr, GhostMap, and Paradox).

When we executed the Amazon Mechanical Turk (AMT) experiment, it was a resounding success. TA1 teams completed more work in shorter time periods with larger and more diverse crowds than they had achieved with the games. The cost of this effort was minimal for the three teams. The specific results of these AMT experiments are fully addressed in the final reports for Kestral, University of Washington, and Raytheon BBN. In future programs, we strongly recommend exploring both a payment-based crowd sourcing approach and a game-based crowd sourcing approach. In particular, starting with a payment-based approach that is less expensive to initialize can enable a program to provide immediate benefit, and can provide more time to develop effective game-based techniques for more long-term engagement of citizen science contributors.

3.6.2 Crowdsourced Formal Verification Using TopCoder Bug Hunt

We performed an additional investigation of paid crowd sourcing using a TopCoder Bug Hunt. For each of the five games, we ran a Bug Hunt Event in which TopCoder community members were paid to find bugs in active game levels for each game. Players were only paid for finding bugs in actual game levels, not in tutorials, thereby ensuring that they would work against the FV task while finding those bugs.

Table 3 shows the results of these Bug Hunts, both in terms of the game progress achieved by the TopCoder community, and in terms of the number of verified issues found in the games (while the latter was not a primary objective of this study, if it had been done earlier in the program, it would have been a very useful outcome).

Table 3 Bug Hunt Results

	Binary Fission	Dynamakr	Hyperspace	Monster Proof	Paradox
Progress	Levels Completed: 332	Score Generated: 21,404,539	Levels Completed: 79	Levels Completed: 4,503	Levels Completed: 1660
Valid Issues Reported	20	47	25	65	36

This approach resulted in significant work achieved, but at a higher cost than the Mechanical Turk approach. In addition to achieving this work, the TopCoder community identified numerous errors (on average, 38 per game) not yet identified in previous testing and evaluation by game players or AMT participants. This added value can be particularly useful in the early part of a release period, because it allows game developers to improve the software to engender more gameplay in the future.

3.6.3 Increasing Participation with Contests and Marketing

Finally, we explored a marketing and reward-based approach to incentivize game play and performance. In particular, several weeks after the Phase 2 game release, we ran a community contest that provided the best performers with in-game rewards and an opportunity to participate in a webinar with the game developers. We gained useful feedback from these performers and evaluated whether the marketing effort that identifies this incentive mechanism increased overall participation and outcome from the game community.

We generated rules for this contest (see Appendix H) and generated a public announcement, all approved by DARPA. While we originally intended to have travel-based prizes associated with this contest, we determined that these prizes were too difficult to manage in the current funding format. Instead, we rewarded performers with game- and website-based accolades and, for the best performers, participation in a webinar with the TA1 developers. We started this contest in late-July, and executed it for two weeks to evaluate its impact on participation within the Verigames website.

When we executed the contest, it had a clear impact on people logging into the website. However, for some of the individual games, this impact did not transition to actual gameplay (for example, Ghost Map Hyperspace and Dynamakr only had one and two players achieve progress during the contest, respectively). The most successful elements of the contest were with Binary Fission and Monster Proof, where the contest winners interacted heavily with the game developers to ask questions and provide feedback, ultimately helping to improve the games. In future efforts, we recommend coupling contests with developer interaction to engender participation and improve the outcome of the contest.

In October, we held the Contest Winner WebEx Event, the prize for the winners of the contest; the results of this event are discussed in Section 3.5.5.

3.7   Market CSFV

We continued the marketing efforts started in the earlier segment of the CSFV effort, focusing on a combination of website branding, public relations, and marketing events designed to attract attention to CSFV crowd sourcing methodologies. This effort was led by GameDocs and Ms. Belinda Van Sickle. The main focus of these efforts was on marketing:

- Phase 2 games
- Mechanical Turk tasking
- Performance-based prize opportunities

Table 4 lists the specific marketing strategies used for the CSFV effort.

Table 4: Marketing Strategies

Marketing Method	Description
Website Branding Strategy	Suggest changes to the website based on the games as developed, including creating overall themes, branding assets, and other components that are more relevant to the Phase 2 games.
Public Relations	Create public relations materials including press releases, PR articles, social media marketing messages, and email blasts for the three elements identified above. PR staff includes Belinda Van Sickle and subcontractors of GameDocs, including successful game industry PR agencies.
Media Buys	Purchase online advertising on appropriate sites based on marketing strategy for each title. Online advertising runs on major social media sites, depending on the audience for each title and contest. Media buying staff include Belinda Van Sickle and other successful game industry PR agencies.
Ad Performance Tracking and Optimization	Track the performance of online advertising on all channels including analyzing where users are coming from, what campaigns are the most successful, and what campaigns are underperforming, with the goal of refining the focus on effective campaigns.

Because the TA1 teams needed to focus on three things for the first few weeks of launch: bug reporting and fixing; usability testing information integration and updates; player community engagement retention work, we ensured our marketing/community management strategy allowed the teams to ensure bugs, usability, community, and engagement received the necessary resources.

The following sections describe the individual marketing activities conducted during the effort. Marketing activities conducted for specific tasks are described in those sections throughout the report.

3.7.1 Marketing Plan

We updated the original 2015 marketing plan to conform to current timeline, budget and game functionality. The marketing plan is detailed in Appendix G. We updated our plan to focus on Citizen Science on verigames.com as well as calls to action. Once users go to verigames.com from various press and other sources, the main call to action is "Play Now." However, if that user is interested in scientific content, the story behind the Verigames project, the science behind DARPA's CSFV program, etc., the call to action is to visit the Citizen Science pages and satisfy their interest through the various content found there. The call to action on the Citizen Science section is "Play Now." Once users have satisfied their scientific interest in the Verigames program and DARPA's CSFV project, the call to action is to play the games. We also updated the plan to focus on community events.

3.7.2 Community Management

We created a strategic plan for Phase 2, which included TA1 participation; required marketing materials; social media plan; verigames.com plan; public relations (PR) integration; online advertising integration; acquisition, conversion and retention plan; and viral marketing. We received DARPA Public Affairs Office (PAO) approval for the community events schedule.

We conducted these events for the TA1 teams, including a live in-game chat, a video series, and live online chats. Three teams' community events were archived on Verigames' online social media. Community events implementation involved extensive technical testing and the creation of instructional materials for TA1 teams and Verigames users. We used Google Hangouts and Google Hangouts on Air technology to allow for live chats and live chats with unlimited users.

These chats are not familiar to everyone and required testing and instructions to ensure they would perform properly during scheduled events. The testing and instructions worked and we had no issues. The community events worked well and the archived versions are up on the Verigames YouTube channel. (Google Hangouts technology offers automatic archiving, although we edited the archived versions to remove blank air.)

3.7.3 Google Adwords Campaign

Small ad buys in fourth quarter 2014 gained market intelligence on what ad buys work for gaining conversion to players.

For our comparison launch ad campaign, we gathered information from TA1 teams on data collected in Phase 1. One team had concrete information; one team had conditional information; and one team had ambiguous information. We compared Phase 1 collected data to real world costs/scale/free up time of formal verifiers. Because the data was not solid, we created a launch campaign that focused on the Citizen Science aspect of Verigames with a minor comparison factor that was deleted so that we could receive approval from the DARPA Public Affairs Office (PAO). Then, we implemented our Phase 2 Google Adwords campaign with PAO approval of ads and repeated revision of ads due to some formatting issues. Analytics showed a spike in verigames.com hits and gameplay and the submission of solutions.

Frequent review of Google Adwords campaign analytics, Logaholics verigames.com site analytics, and in-game play stats from Binary Fission, Monster Proof and Paradox maintained the efficacy of the program. Low performing ads were eliminated and global territories continually optimized to get the best performance from the campaign.

3.7.4 Press Calendar, Press Releases, and Press Kit

We created a press calendar for launch press releases and created press kits for all five games. We compared release service costs and coverage from two vendors and selected the best vendor for the effort. After we received PAO approval, we disseminated press releases through a science-related press service. We uploaded the final press kit to verigames.com and made it available to press outlets. We updated the press kit several times during the effort with updated press releases, updated links, and other material as needed.

3.7.5 Social Media

Social media marketing was a secondary strategy for Phase 2. To serve the citizen scientist market, the verigames.com/in-game sharing focus for Phase 2 was on scientific content. The Citizen Science page content was sharable.

We performed social media marketing through Facebook, Twitter, and Google+. We announced the launch, posted launch content, new blog posts and other new material through these channels. We used paid social media boosting on Facebook and Twitter for all community events and hosted press events.

3.7.6 Newsletters

We published the March 2015 newsletter with previously unpublished content. The April version consisted of a teaser with art and logos of all Phase 2 games. We sent a newsletter with a launch announcement to all registered users shortly after the DARPA web feature was released.

We increased the frequency of the newsletter to provide a forum for promotion of community events and to showcase major press events. Analytics have showed steady user engagement with increased frequency as well as no increase in negative feedback (unsubscribes or marks as spam).

Finally, we delivered a closing Thank You newsletter at the end of November 2015.

3.7.7 Public Relations

We sent an email to several editors/outlets that have covered crowd sourced games in the past and approached outlets that covered launch, offering interviews for feature articles. We received a press inquiry from a BBC reporter and scheduled interviews with TA1 team members, and provided press kit materials and other background information on the effort. We ensured all development team members were apprised with current PAO direction for press contact before their interviews.

We posted the published article on verigames.com, Verigames social media, and in the newsletter. The article resulted in a major spike in gameplay and solutions submitted to the games. We followed coverage of Verigames on online outlets throughout the effort and re-posted content as appropriate to the website, newsletter, and social media.

3.7.8 Clip Reporting

We temporarily hired a clipping service to aggregate all Verigames-related media, but after a 10-day trial, the results missed materials found in dated Google searches, so we did not engage this service.

3.7.9 Contest Materials

We created promotional content for the community contest on the website (News page and drop-down banners) and implemented paid social media marketing, verigames.com promotions, and newsletter promotions. We ensured that the rules and other necessary content were on verigames.com to support the content.

After the contest, winner copy was created and delivered to the contest winners. We announced the winners in the newsletter and on social media, and posted announcements to verigame.com.

3.8   Manage Program

We managed the program and guided the teams through a smooth public launch, multiple contests and events, and maintained the website through November 30, 2015, at which time we removed the games and created a Verigames.com website with links to TA1-hosted websites for their individual games.

Charles River Analytics understands that structured, open, collaborative management is critical to system integration success in large research and development efforts; therefore, we focused on early and continuous coordination and collaboration with the DARPA PM, Government representatives, and other CSFV performers. Our team held weekly coordination meetings and encouraged other performers to test the framework and integrate their components, enabling our team to solve problems in real time. This incremental testing greatly improved the probability of success and reduced schedule risk for all performers during test phases. Charles River also followed a disciplined Program Management process based on the Project

Management Institute's Project Management Body of Knowledge (PMBOK v4), modified for the unique flexibility demanded of successful R&D programs. Our process focused on continuous Quality Assurance and Control, careful Configuration Management, and comprehensive Risk Management; areas that routinely drive successful program results.

Our team was led by Charles River Analytics Inc., who led the analytics effort and managed both the maintenance and update effort and the paid crowd sourcing research. Specifically, Mr. Sean Guarino, Principal Scientist, was the Principal Investigator for this effort, bringing his extensive previous cognitive systems engineering (CSE) and game design experience to guide the assessment of current games, and the evaluation of expert (guru) play styles. Mr. William Dorin, Software Engineer, was the Technical Lead for this effort, guiding the development process, and performing maintenance and engineering tasks where necessary to augment crowd sourced development.

Our team maintained the same team members from the previous effort to work as subcontractors on this effort. Appirio joined us to lead the continuing development effort of the Verigames website and the integration framework. Specifically, Appirio continued to run contests using the TopCoder community to achieve maintenance and development tasks, augmenting the framework to incorporate both Phase 2 games and task-oriented approaches for Mechanical Turk. By maintaining Appirio in this role, we continued to have access to Mr. Ambi Del Villar and Mr. Ahmad Alkhawaja, who are both intricately familiar with the existing code base. Our team was also joined by GameDocs, led by Ms. Belinda Van Sickle, who continued to lead the marketing effort for CSFV. Supporting Ms. Van Sickle, we continued to include YouEye on our team to gather and run users for evaluations of CSFV. Our team tactically used other companies who reviewed Verigames in Phase I, including WhiteHat Security to evaluate the security of the updated Verigames site.

The organization of our team is shown in Figure 5.
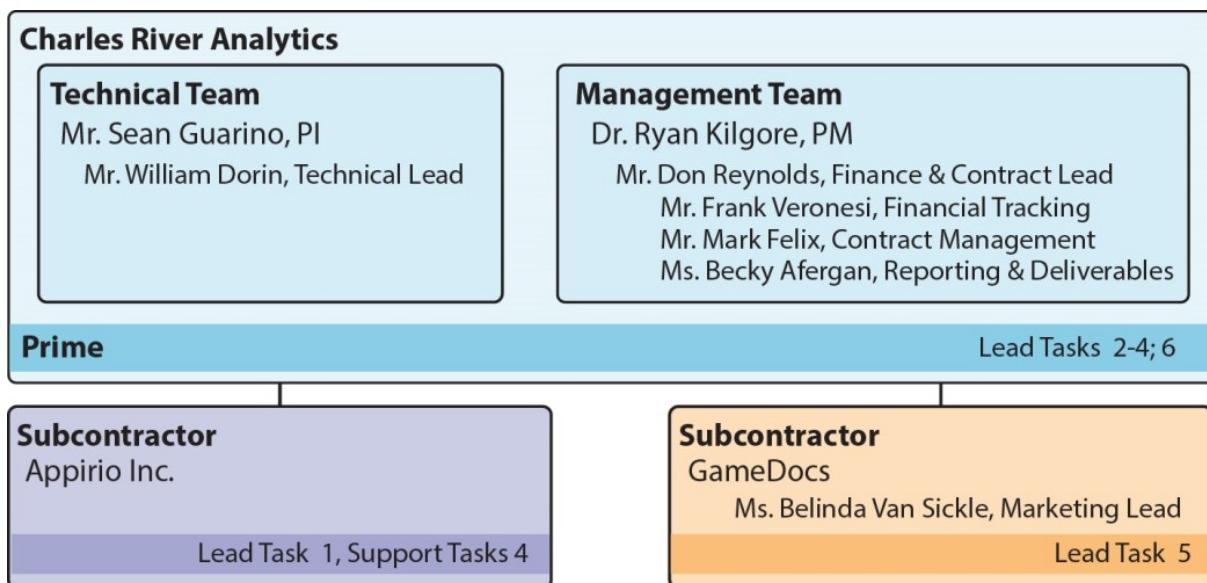
Figure 5 Program Organization

Charles River's process for achieving program cost, schedule, and performance goals is based on a practical and proven process that focuses on responsiveness and accurate information products for our Program Managers. This process, shown in Figure 6, works particularly well for integrating scientific and R&D programs that require management of frequently changing requirements.
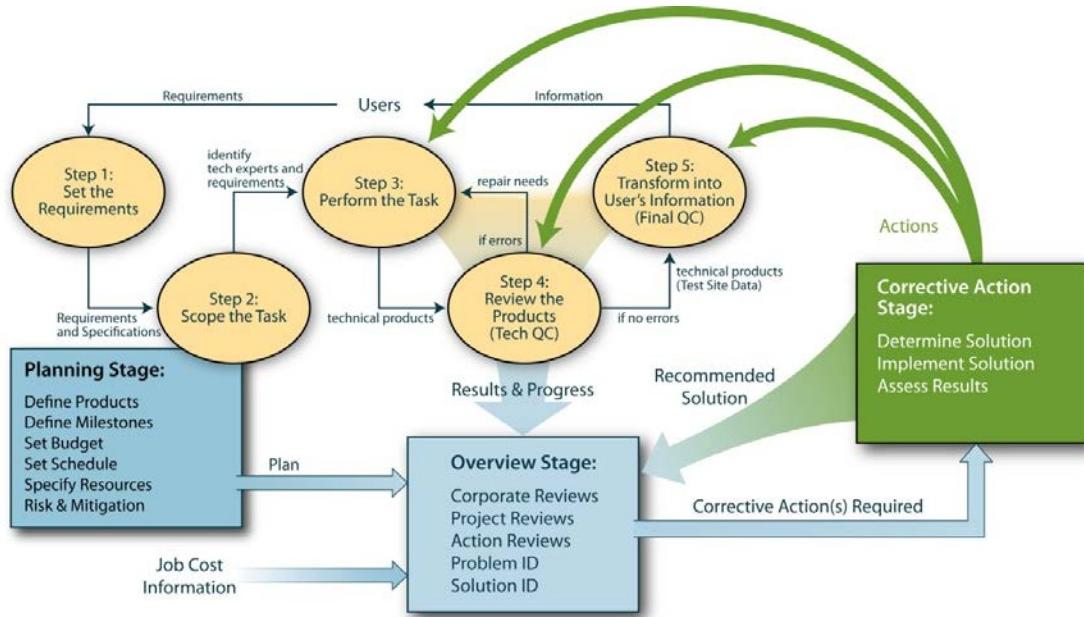
Figure 6 Charles River's Cost, Schedule, and Performance Management Process

Our process consists of: the following three stages:

- Planning Stage – Determines the cost, schedule, and performance requirements and the metrics for monitoring progress. The Planning Stage identifies project risks and mitigation approaches; suitable project metrics, resources, and the budget; schedule milestones, and products for operational tasks.
- Overview Stage – Monitors progress against the metrics. In the Overview Stage, we analyze results and progress indicators from the operational tasks, which include performing the work, reviewing the products, and producing the deliverables. We also produce and monitor biweekly budget data.
- Corrective Action Stage – Recovers cost, schedule, and performance compliance when problems arise. The key to achieving this compliance is early detection of problems and quick action, enabled by our agile software engineering process. In the Corrective Action Stage, the PM works in concert with team members and the customer to determine and implement the best solution for recovering from a cost, schedule, or performance deviation.

This process is effective, responsive, predictive, and our experience has demonstrated it responds quickly to changing requirements.

Because R&D programs are risky, the Program Manager must implement a robust, structured risk management process to ensure program success despite uncertainties. Charles River aggressively managed, mitigated, and reduced risk throughout the life of the program. This process began during proposal development and continued through the program as potential risks were identified, analyzed, and classified. Risk mitigation and reduction strategies reduced the

probability of certain risks occurring. Our team also developed strategies for any risks that threatened program success (see table 5).

Table 5 Program Management Risks and Mitigation Plans

Management Plan Risk	Mitigation Plan
Inter-team communications	Our subcontractor and consultant had clearly stated tasks focused on regular reporting and interaction with Charles River as the Prime Contractor; all parties agreed to attend team meetings and support team events as well as Program events.
Interactions with other CSFV performers	Regular Technical Interchange Meetings (TIM) with all performers clearly established interface standards early and regularly. Our agile engineering process produced informal software drops every two weeks so that other performers could identify areas of potential concern without waiting for formal code drops.
Delayed component releases from TA1/TA2	Our agile engineering approach encouraged regular releases of components from CSFV performers. All performers worked with Charles River to ensure that components were delivered on time and that any obstacles to those releases are cleared efficiently.
Execution of commercial contracts	We reviewed contract needs with Appirio and other commercial contractors in advance, and were comfortable that we could negotiate a commercial contract with the company; however, there was a small risk that there would be necessary flow down clauses from the AFRL contract that proved unacceptable to Appirio. Should those issues have proved unsurmountable, we were prepared to bring on Mr. Ahmad Alkhawaja as a direct consultant to transition ownership of the software to the Charles River engineering staff.

Because risk management is not a onetime event, Charles River Analytics' program teams continuously monitored program risk at our internal monthly program reviews to reevaluate the status of risks tracked on the Risk Register and identify any new risks that occurred as a result of work during the previous period. All team members were encouraged to identify risks to the Program Manager and Principal Investigator at any time.

4.   SUMMARY OF RESULTS

Overall, the CSFV-A program was a strong success. Working with the TA1 game development teams, we successfully managed the release of the Phase 2 games, performed analysis of those games, and assessed additional incentive mechanisms for future crowdsourcing efforts.

Our primary focus during the effort was to manage the Verigames website and integration framework. In support of this, we updated the website to enable the integration of the Phase 2 games, and managed both the initial friends & family release of the games, and the public release of those games. In updating the website, we built a *Citizen Science* page that helps to reframe CSFV as a citizen science effort, rather than a gaming effort, providing a variety of information to the community on the purpose and underlying technology for CSFV. Throughout the effort, we addressed software and integration issues that were identified by the TA1 teams in a timely manner, and ensured that the website was consistently maintained in this period. At the close of the effort, we transitioned the website to a simpler, static version of the website that maintains the citizen science information, but primarily provides a long-term pointer to games that are maintained by TA1 teams.

Another key focus of our effort was analytics involving the CSFV games. We primarily focused on two types of analytics that were identified as most useful by the TA1 teams: (1) expert game design analysis and (2) user studies. We performed deep reviews of the games with our expert game designers, providing early feedback to the teams to help improve the games. Then, for much of the effort, we held biweekly game design meetings with the majority of the TA1 teams to address common issues across the games. Also, during the friends & family release period, we worked with YouEye to perform a user analysis of the games, gathering key user feedback on pain points in the game. Each of these techniques were identified as very useful by the TA1 teams to drive their game design and refinement.

Other analytical efforts were less useful. In particular, we did manage interactions with game gurus, and acquired some useful feedback from those gurus. However, while game gurus did perform well on their games, all indications were that this was based primarily on time commitment, not on any kind of a discernable or useful game strategy. Therefore, we were not able to make valid recommendations for tutorial improvements or automation, beyond addressing guru issues with tutorial clarity and usefulness. Finally, our computational analytical efforts also provided minimal benefit; we identified several important trends in play style, but these did not generate recommendations for game improvements. In general, this effort was impacted by the same issues we had in our previous work—the ability to analyze play patterns was strongly limited by the limited number of repeat players across the games.

Another key objective of our effort was to enable and help to assess alternative incentive mechanisms for driving crowdsourced formal verification. Largest amongst these efforts was our work supporting the TA1 teams with an integration framework for using Amazon's Mechanical Turk to acquire participants and address formal verification problems. The use of AMT was a resounding success, with results that in many ways surpassed those of the game-based crowdsourcing. The details of these results are captured in the relevant TA1 final reports; however, we strongly recommend using AMT-based crowdsourcing in future citizen science efforts as an early and inexpensive method to engender participation.

We also explored TopCoder Bug Hunts as another payment-based approach to engender participation. This was also a success, as members of the TopCoder community solved a large number of puzzles in the games as they tried to address bugs. However, this is dramatically more expensive than the AMT-based approach. Still, early on in a game-based effort, this can be very useful, as it does not only address the underlying citizen science objectives, but also provides numerous bug reports that game developers can address to ensure that the game is more stable and engaging for free participants.

Finally, we explored a contest-based incentive mechanism that was ultimately unsuccessful, as it did not drive increased participation for the games. We were not really able to run the contests that we had intended due to payment restrictions on Government contract vehicles; in the long term, we recommend refining these kinds of contests to incorporate more substantial rewards from an early point in the effort, and further test if they can be useful in gamified crowdsourcing efforts.

In addition to these primary technical thrusts, throughout the effort, we successfully managed cross-team collaboration, successfully marketed CSFV with the aid of GameDocs, and managed the execution of the CSFV integration effort.

5. CONCLUSIONS AND RECOMMENDATIONS

Overall, we are pleased with the success of our integration effort in the CSFV program. We successfully updated and maintained the verigames.com website to enable the deployment of the Phase 2 games, and the collection of player-generated solutions and performance data on those games. Overall, releases were done in a timely manner with respect to the targeted schedule, and the website was stable through the release of those games. Further, the software we built for that distribution provides an environment that could potentially be reused in future applications, providing a basic carousel format that enables the simple presentation of a range of citizen science solutions.

We are also particularly pleased with the results of our key expert and user analytics in evaluating the five games developed by TA1 teams. Across the CSFV effort, we were able to make significant recommendations that contributed to game improvement, helping the game designers to find and address key flaws in their games. For future game-based citizen science efforts, we would recommend similar analysis efforts. By reviewing games with expert game developers, and holding cross-team game design meetings, the overall development community is able to generate better games, improving engagement, usability, and tutorial effectiveness.

User studies are similarly essential to effective game development, providing critical feedback on which elements players are finding difficult to comprehend or use. Indeed, more standard game communities use beta releases of the game as a means to enable effective user studies and user-driven improvements to games. For future efforts, we recommend supporting an early, interactive beta-testing community to evaluate and improve these games. Some of the biggest improvements made to games in CSFV happened because developers were directly interacting with the TA1 developers; in future citizen science efforts, we recommend enabling that kind of interaction across the program. The community would be better served with an early release of game concepts—even if those concepts are not fully operational—to start getting user feedback from an early stage. Furthermore, involving users in this way in the community would foster a greater sense of community involvement, which in turn would have the potential to motivate further participation when the full games are released, and data is being collected.

Another key success in the effort was the use of Amazon's Mechanical Turk and TopCoder's Bug Hunts to generate additional game play and problem solving. Both payment-based approaches were very successful in increasing community contributions. AMT, in particular, generated better results than the games, in a shorter period, and for relatively low cost. The Bug Hunts were more expensive, but also generated a large amount of solution traffic and at the same time identified numerous game bugs that could be resolved to improve the community experience. In future efforts, we strongly recommend using payment-based crowdsourcing as a starting point, beginning the effort with tools like AMT, where the initial focus is simply to crowdsource the problem, and later introducing concepts such as gamification, where the focus is to extend that capability to a tool with long-term viability (e.g., a tool that citizen scientists will contribute to without payment).

We experienced several limitations with respect to other elements of the CSFV-A program. One of our key objectives was to analyze the behaviors of game gurus—those game experts who were responsible for generating the largest contributions to proofs. We had originally thought that such experts might have game strategies and approaches that would be useful to share with other players or to incorporate into underlying automation for formal verification. Ultimately, we

had two issues in executing this research. First, due to the constraints on the funding mechanisms for these gurus, we were unable to find many gurus willing to participate in an event. In the future, we recommend using more online interactions to control these costs, as we were more successful in fostering participation in online meetings with contest winners. More importantly, the gurus who contributed most effectively to these games did not actually appear to be using strategies in the games; rather, they were the individuals that played the games the most. Nevertheless, it was useful to engage the game gurus, primarily because they understood the game experience and were able to provide detailed and essential feedback that can improve the game experience. In future research, we recommend early engagement with high-volume players on a regular basis to understand what they like and do not like about the game. These players are the real contributors in a citizen science community, and game improvements should be made with their engagement as a primary goal.

With respect to computational analytics, the key issue that we had throughout the effort was a lack of good data from the games. Part of this issue stemmed from limited collection and delivery of data from some of the game environments, but most of the issue arose from the very limited player population. Nevertheless, we were able to do some basic analyses of game characteristics that seemed to be most linked to attrition, and were able to provide some reasonable data to TA1 teams to guide game improvements. Overall, even when we were successful in identifying these patterns, the information provided was not as useful to TA1 teams as information provided by expert game designer analyses or user studies.

Finally, we did hold a single contest late in the effort to try to increase participation rates. While it had a minor effect on traffic on the Verigames website, its impact on actual game play was negligible. Part of this may be because of the limited prizes we were able to provide (i.e., no cash or material prizes; prizes were limited to accolades in the game environment and/or social meetings with game developers). Nevertheless, we believe that more regular contests that are well-integrated into the game environment and the games themselves can provide a method to increase traffic, and is worth investigating further in future efforts.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

ACRONYM	DESCRIPTION
3D	Three Dimensional
GSE	Gamification in Security Education
AFRL	Air Force Research Laboratory
AMT	Amazon Mechanical Turk
API	Application Programming Interface
AWS	Amazon Web Services
CPU	Central Processing Unit
CSE	Cognitive Systems Engineering
CSFV	Crowd Sourced Formal Verification
DARPA	Defense Advanced Research Projects Agency
DEPEND	Detection, Explanation, and Prediction of Emerging Network Developments
DNS	Domain Name System
E&RM	Exploitation and Resource Management
EMIAT	Evolvable Microgames for Information Assurance Training
FV	Formal Verification
GUARD DOG	Group Understanding & Analysis for Rapid Detection – Deployed on Ground
HIT	Human Intelligence Task
HMI	Human Machine Interface
IA	Information Assurance
INTERAACT	Interface for Enhanced Analyst/Automation Collaborative Tasking
JAGUAR	Joint Air/Ground, Unified, Adaptive Replanning
MAAGI	Malware Analysis & Attribution using Genetic Information
MITM	Man-in-the-Middle
PAO	Public Affairs Office
PI	Principal Investigator
PM	Project Manager
PMBOK	Project Management Body of Knowledge
PR	Public Relations
QA	Quality Assurance
QC	Quality Control
SME	Subject Matter Expert
TIM	Technical Interchange Meetings
TA1	Technical Area 1 of the CSFV Program
TA2	Technical Area 2 of the CSFV Program
US	United States
VM	Virtual Machines

Appendix A.   Integration Activities

Table 6 summarizes the issues addressed as part of the integration activities during the effort.

Table 6 Integration Issues

Issue Type	Priority	Status	Summary
Helpdesk Ticket	Major	Open	After /verifySession, what should we do with userId?
Bug	Minor	Resolved	"Cannot upload photo" error on verigames.com
Bug	Major	Resolved	Problem adding score records to api.dynamo.verigames.org - error 400
Task	Major	Resolved	Create Forum categories for Beta testing
Task	Major	Resolved	Create email blast; add lists on MailChimp
Helpdesk Ticket	Critical	Resolved	Change to binaryfission domain name
Bug	Major	Resolved	Dynamo - Can't get user info using "Resource Owner Credentials Grant" Oauth. Returns "not authorized"
Bug	Major	Resolved	The login page as part of Oauth redirect does NOT include a "forgot password" link.
Bug	Major	Resolved	Error returned when calling Scoring api – 400. The query parameter "playerIds" should be valid array of strings.
Bug	Major	Resolved	Look at .org pw functions
New Feature	Major	Resolved	At Ghost Map Classic address (ghostmap.verigames.com), add landing page
Task	Blocker	Resolved	Point binaryfission.verigames.com to 54.80.74.119
Environment Setup	Blocker	Resolved	[Binary Fission] Turn off web proxy/pipeline behavior for binaryfission.verigames.COM
Bug	Blocker	Resolved	[Binary Fission] Cannot get Disqus token from verigames.com endpoint.
Task	Major	Open	New Games page redesign
Task	Major	Open	Implement Achievements/Leaderboards page
Task	Major	Open	Add Attached Videos to Citizen Science Page
Task	Major	Open	Add Attached Bibliography to Citizen Science Page
Task	Major	Open	Add Attached Media Articles to Citizen Science Page
Task	Major	Open	Add Attached Blog Posts to Citizen Science Page
Bug	Major	Resolved	api.monsterproof.verigames.com gives an error - connection refused.
New Feature	Major	Resolved	Phase 2 Assets: Monster proof
Environment Setup	Critical	Open	Apply security updates on m2.verigames.org
Task	Major	Resolved	Create F&F URLs and exclude from indxexing
Bug	Major	Resolved	Setup Dynamo Production Servers
New Feature	Major	Resolved	Link from hyperspace.ghostmap.com to http://ghostmap.verigames.com/pbgserver/ hyperspace.html
Bug	Blocker	Resolved	Set up Monster Proof Production Game Server
Bug	Major	Resolved	502 error when posting to Gaming API
Bug	Blocker	Resolved	Set up Monster Proof Production Verification Servers
Bug	Major	Resolved	Add "a.dynamo.verigames.com" to the Domain Name System (DNS) and route file to forward to "10.1.4.85:3000"
Task	Blocker	Resolved	OAuth not working on Monster Proof Production
Bug	Blocker	Resolved	Cannot finish authenticating
Bug	Major	Resolved	Dynamo Production 'backend' server - private key refused

Issue Type	Priority	Status	Summary
Task	Major	Resolved	UW requirements for Friends and Family
Task	Major	Resolved	Setup - external names of verification Hosts
Task	Major	Resolved	Fwd: Binary Fission Disqus
Task	Major	Resolved	Re: api.stormbound.verigames.com is down
Task	Major	Resolved	Re: api.stormbound.verigames.com is down
Task	Major	Resolved	Re: Logging in on Staging
Sub-task	Major	Resolved	CSFVDEV-431 Authentication for Phase II verification servers
Task	Major	Resolved	Get Lenny and Sean Details to the Data collection API requested by Will
Bug	Major	Resolved	Get Disqus token from the server
Task	Blocker	Resolved	api.stormbound.verigames.com is down
Task	Major	Resolved	Re: Logging in
Task	Major	Resolved	Re: Logging in
Task	Major	Resolved	OAuth2 - what is our "client secret" number?
Task	Major	Resolved	Verigames API bug
Task	Major	Resolved	Re: Verigames API bug
Task	Major	Resolved	Using iPad app
Bug	Major	Resolved	Verigames.org password reset doesn't work- clicking email link displays an error
Bug	Major	Resolved	Dynamo - OAuth post returns SSL Certificate problem
Task	Major	Resolved	Phase 2 testing environment for Paradox
Task	Major	Resolved	Correct two grammatical errors in verigames.com FAQ section
Environment Setup	Critical	Resolved	Apply security updates on m2.verigames.org
New Feature	Major	Resolved	Phase 2 Assets: Monster proof
Bug	Major	Resolved	monsterproof gaming api gives different responses than the stormbound api
Bug	Major	Resolved	Dynamakr - Scores search ignores input parameters
Bug	Blocker	Resolved	This ticket (and all others) is publicly visible
Task	Major	Resolved	Implement Achievements/Leaderboards page
Task	Major	Resolved	New Games page redesign
Bug	Major	Resolved	Problem adding score records to api.dynamo.verigames.org - error 400
Bug	Major	Resolved	502 bad gateway for api.binaryfission.verigames.com/api/me
Helpdesk Ticket	Major	Resolved	After /verifySession, what should we do with userId?
Task	Major	Resolved	Update verigames.com for Phase 2: Update Copyright Info on verigames.com Footer
Task	Major	Resolved	Update verigames.com for Phase 2: Add New Games Categories to Forums
Task	Major	Resolved	Update verigames.com for Phase 2: Delete Awards Module on Flow Jam Games Page
Bug	Minor	Resolved	"Cannot upload photo" error on verigames.com
Task	Major	Resolved	Create Forum categories for Beta testing
Bug	Major	Resolved	Dynamo - Can't get user info using "Resource Owner Credentials Grant" Oauth. Returns "not authorized"

Issue Type	Priority	Status	Summary
Bug	Major	Resolved	The login page as part of Oauth redirect, does NOT include a 'forgot password' link. Big hurdle for friends and family
Bug	Major	Resolved	Error returned when calling Scoring api - 400 The query parameter "playerIds" should be valid array of strings...
Bug	Major	Resolved	Look at .org pw functions
New Feature	Major	Resolved	At Ghost Map Classic address (ghostmap.verigames.com) add landing page
Task	Blocker	Resolved	Point binaryfission.verigames.com to 54.80.74.119
Environment Setup	Blocker	Resolved	[Binary Fission] Turn off web proxy/pipeline behavior for binaryfission.verigames.COM
Bug	Blocker	Resolved	[Binary Fission] Cannot get Disqus token from verigames.com endpoint.
Bug	Major	Resolved	api.monsterproof.verigames.com gives a error connection refused.
New Feature	Major	Resolved	Link from hyperspace.ghostmap.com to http://ghostmap.verigames.com/pbgserver/hyperspace.html
Task	Blocker	Resolved	OAuth not working on Monster Proof Production
Bug	Blocker	Resolved	Cannot finish authenticating
Bug	Major	Resolved	test
Task	Major	Resolved	Fwd: Binary Fission Disqus
Task	Major	Resolved	Re: ** PROBLEM alert - stormbound.verigames.com/HTTP **
Task	Major	Resolved	Re: Bug in your bug-finding-game's website
Task	Major	Resolved	Re: Bug in your bug-finding-game's website
Task	Major	Resolved	Re: Bug in your bug-finding-game's website
Bug	Major	Resolved	MTurk API returning "502 Bad Gateway" when calling /generateToken
Task	Major	Resolved	Mturk verigames access
Bug	Major	Resolved	Requesting OAuth access token for MTurk API for Dynamakr
Task	Major	Resolved	Requesting access to https://mturk.verigames.org
Task	Major	Resolved	Fwd: ** PROBLEM alert - stormbound.verigames.com/HTTP **
Task	Major	Resolved	Register bug in IE11
Bug	Minor	Resolved	Notification links take you to wrong URL
Task	Major	Resolved	Replace current verigames.com "About Us" page text with attached text
Task	Major	Resolved	Remove "Press Kit" From Links in verigames.com Header and Footer Navigation
Bug	Trivial	Resolved	User icon doesn't show up in Authorize window
Bug	Blocker	Resolved	Restart TC servers for StormBound
Task	Major	Resolved	Request access to mturk web dashboard
Task	Major	Resolved	Change the Word "Interview" to :Videos" in the Citizen Science pages
Task	Major	Resolved	Delete Podcast/Audio Module on Citizen Science Pages and Replace with Additional Video Content
Task	Major	Resolved	Access verigames.com Citizen Science Pages from Main verigames.com Website
Improvement	Major	Resolved	Excessive visits to Authorization page when starting Binary Fission
Bug	Blocker	Resolved	api.monsterproof.verigames.com gives an error when requesting score
Task	Major	Resolved	Add "Play Now" Buttons Throughout verigames.com Citizen Science Pages
Task	Major	Resolved	Make the word "Articles" Plural in the "Scholarly Articles" Heading in the Citizen Science Pages

Issue Type	Priority	Status	Summary
Task	Major	Resolved	Please switch infographics on verigames.com Citizen Science pages
Bug	Major	Resolved	monsterproof.verigames.org rejecting root login
Task	Major	Resolved	Create "Play Now" Button for verigames.com Citizen Science Pages
Task	Major	Resolved	Delete Greek Text on Citizen Science Page
Task	Major	Resolved	Images for Citizen Science Blog Post Section
Bug	Critical	Resolved	I Agree Button Not Activating Correctly for New Account
Bug	Blocker	Resolved	monsterproof staging oauth not returning auth code
Bug	Major	Resolved	502 bad gateway for oauth.verigames.org/oauth2/authorize
Task	Critical	Resolved	Create additional VMs for "monster proof"
Task	Major	Resolved	Additional staging server HTTPS proxy for MonsterProof
Bug	Major	Resolved	Mturk api: create hit complaining that "url should be a string" in 400 bad request
Task	Critical	Resolved	Deploy verigames.com Advertising Banner ASAP for Binary Fission Wednesday July 1st Event
Task	Major	Resolved	Add Monster Proof Approximate Lines of Code Verified Feed to Citizen Science Home Page
Task	Major	Resolved	Need cross domain file to allow calls from game page swf to turk api: https://mturk-api.verigames.org/crossdomain.xml
Bug	Major	Resolved	PHP scripts not running on Paradox staging server
Task	Major	Resolved	Mechanical Turk - Add interface to Hit Create Page to change AutoApprovalDelayInSeconds
Bug	Major	Resolved	Mturk when creating hit URLs the ?token=#### is being added even if querystring params already exist in the specified URL
Bug	Major	Resolved	Dynamakr Mechanical Turk - Turk submission shows empty Task Id
Task	Major	Resolved	Need http://ec2-184-73-33-59.compute-1.amazonaws.com/turk/ to be visible
Bug	Major	Resolved	vs4.monsterproof.verigames.com pointing to incorrect server
Bug	Major	Resolved	Mturk Api: Attempt to DELETE hit by hit id yielded Internal Server Error and "Hit with id=XXX does not exist" message
Task	Major	Resolved	Re: (CSFV Turk) 502 Bad gateway on turk API
Bug	Major	Resolved	Blacklist
Bug	Major	Resolved	MonsterProof staging proxy HTTPS certificate issue
Task	Major	Resolved	Monster Proof Production is down
Task	Major	Resolved	Re: Access to Logaholics?
Task	Major	Resolved	Re: Monster Proof Production is down
Task	Major	Resolved	Re: Monster Proof Production is down
Task	Major	Resolved	Fwd: Verigames.com issue and Jira issue
Bug	Blocker	Resolved	Monster Proof is getting Failed to load resource: net::ERR_INSECURE_RESPONSE errors
Bug	Minor	Resolved	Monster Proof Staging needs same routing setup as production
Task	Major	Resolved	Create Drop-Down Banner for High Scorer Contest
Task	Major	Resolved	OAuth servers down for Monsterproof?
Bug	Major	Resolved	Add Verigames Logo to High Score Contest News Post
Bug	Major	Resolved	Add High Scorer Contest Rules to verigames.com
Task	Major	Resolved	Please fix the following errors on verigames.com Citizen Science page

Issue Type	Priority	Status	Summary
Bug	Major	Resolved	Error popup - Achievements page
Task	Major	Resolved	Technical problems Chris
Task	Major	Resolved	Account management samuel.yeom
Task	Major	Resolved	Remove verigames.com drop-down banner for now
Task	Major	Resolved	Dynamakr - Add a "Dynamakr Community Stats" panel to the Citizen Science Page
Task	Major	Resolved	Update verigames.com Drop-Down Banner
Bug	Major	Resolved	MTurk qualification requirement not being properly added upon HIT creation
Bug	Major	Resolved	Mechanical Turk front end panel- View Assignments - Clicking column headers does NOT re-sort records
Bug	Major	Resolved	Mechanical Turk - View Events - Date column incorrect (shows 51 days ago)
Bug	Major	Resolved	Mechanical Turk - View Assignments - Does NOT display more than 10 HITS
Bug	Major	Resolved	Dynamakr -the 'How to Play' info graphic is positioned to high, vertically. The top of the words 'How To play the game' are cut off
Bug	Major	Resolved	Mechanical Turk - Error during Create Hit - insufficient funds
Bug	Major	Resolved	Dynamakr Mechanical Turk - Need to change HIT description
Task	Major	Resolved	Other Paul Rubens
Task	Major	Resolved	Other Paul Rubens
Bug	Major	Resolved	Mturk qualifications not being granted with autoApprove
Bug	Major	Resolved	Turk API getAssignment / grant bonus returning 500 error
Bug	Blocker	Resolved	Monster Proof videos don't fit on page
Bug	Major	Resolved	Mturk api: create hit complaining that "url should be a string" in 400 bad request
Bug	Major	Resolved	[Forum]user can upload any file
Bug	Major	Resolved	[Forum][286]SQL injection Work
Bug	Major	Resolved	[Forum][272]SQL injection Work
Bug	Trivial	Resolved	[Profile] Layout Issue when we edit email notifications
Bug	Major	Resolved	[Forum]Email validation not done
Bug	Trivial	Resolved	[Profile] 'Messages' Tab is not working
Bug	Major	Resolved	[Forum]Search Not Working Properly
Bug	Major	Resolved	[Forum][318] visitor can download the attachment
Bug	Trivial	Resolved	[Home] Games Menu overlap with the Social Media content set
Bug	Major	Resolved	[news][134][135][140][141]Like button missing
Bug	Major	Resolved	[Forum][293]Show result
Bug	Major	Resolved	[Forum][247]Show result
Bug	Major	Resolved	[Profile] You can add yourself as a friend
Bug	Major	Resolved	[Login] Remember me not working
Bug	Trivial	Resolved	[Dynamakr] Clicking on SIGN IN won't load it as a pop up (as in other tabs)
Bug	Minor	Resolved	[Home] No Space in between Twitter Name and Twitter button
Bug	Major	Resolved	[dynamakr] Screenshot status Overlap with Back button
Bug	Trivial	Resolved	[News/Games] Same section but the functionality is different
Bug	Trivial	Resolved	[Home] Home page slider is not smooth in FF

Issue Type	Priority	Status	Summary
Bug	Major	Resolved	[WHAT'S HOT?]Comment icon missing
Bug	Major	Resolved	[Home] [Search]search list is not closing
Bug	Major	Resolved	[Games][39] "Search Members" text field
Bug	Trivial	Resolved	[Citizen Science] URLs are not clickable
Bug	Major	Resolved	[Citizen Science] [All]Banner is too short With Play button
Bug	Major	Resolved	[Citizen Science] [interviews] [blog] [media] twitter Scroll bar is disabled
Bug	Minor	Resolved	[Forum] Advanced Search is not working
Bug	Major	Resolved	Forun Recent Post should be in ascending order
Bug	Major	Resolved	Signout is enabled even though the user plays as a guest
Bug	Major	Resolved	[Citizen Science][All] Text overlaps videos
Bug	Major	Resolved	[Citizen Science][Blog] None of the links work
Bug	Major	Resolved	[Footer][183] Verigames hyperlink is incorrect
Bug	Trivial	Resolved	[Citizen Science][All] 'Verification facts discovered' section overlap with each other
Bug	Trivial	Resolved	[Citizen Science][Blog] 'View More' button is not working
Bug	Major	Resolved	INFOGRAPHICS moves out of screen
Bug	Major	Resolved	Screenshot number overlaps the back button image
Bug	Major	Resolved	Videos do not play
Bug	Trivial	Resolved	[Forum][] Layout Issue in the WATCHED button
Bug	Major	Resolved	[Sign-up page] it should ask user to enter the Password once again while signing up
Bug	Major	Resolved	[Forum][] Can't DELETE a single post reply in a thread
Bug	Major	Resolved	[Forum][111-112] Can't DELETE a thread
Bug	Major	Resolved	[Send Message] chat is not working
Bug	Trivial	Resolved	[Forum][129] Can't PIN a thread
Bug	Major	Resolved	[Forum][177] Can't lock a thread
Bug	Major	Resolved	[Password recovery] cannot receive password recovery email
Bug	Major	Resolved	[Password recovery success page] a dot should be removed in the confirmation message
Bug	Major	Resolved	[Contact-us page] the text box can be dragged out from the form boundary
Bug	Major	Resolved	[Home page] contest rules page cannot be accessed
Bug	Major	Resolved	[News page] long values in the dropdown list cannot be displayed fully
Bug	Minor	Resolved	Confirmation message not valid for email subscribe
Bug	Major	Resolved	After Login won't redirect the page to Main Page
Client Task	Critical	Resolved	Need account information for contest winners.
Bug	Major	Resolved	CSFV Event BAnner Design Task
Bug	Major	Resolved	fix chat configuration
Bug	Major	Resolved	CSFV Merge Branches
Bug	Major	Resolved	[sdgun] IE Bug Hunts - Additional Payment
Bug	Major	Resolved	[Saxophonist)] IE Bug Hunts - Additional Payment
Bug	Major	Resolved	[macs054] IE Bug Hunts - Additional Payment
Bug	Major	Resolved	[dpebble] IE Bug Hunts - Additional Payment

Issue Type	Priority	Status	Summary
Bug	Major	Resolved	[karthikbecse] IE Bug Hunts - Additional Payment
Bug	Major	Resolved	Fixed Styling in Science page
Bug	Major	Resolved	[Forum]user can upload any file
Bug	Major	Resolved	[Forum][286]SQL injection Work
Bug	Major	Resolved	Social Media Promotion Payments : July 2015
Bug	Major	Resolved	Social Media Promotion Payments : August 2015
Bug	Major	Resolved	After loading High score configuration, the score is different in the game section
Bug	Major	Resolved	When the map zone is over buttons these cannot be used
Bug	Major	Resolved	While loading the game the scores are shown as more than 100% some times which is incorrect
Bug	Trivial	Resolved	[Common][Levels] When we Zoom In; Optimizer selection circles won't zoom In
Bug	Major	Resolved	Annoying text area - High scores Click on a score to load it - Appears every few minutes
Bug	Major	Resolved	Lost zoom out function
Bug	Major	Resolved	Game not Loading on Firefox
Bug	Minor	Resolved	A value of score improvements is negative
Bug	Minor	Resolved	Scores are more than 100%
Bug	Minor	Resolved	Score with title
Bug	Minor	Resolved	Duplicate Username in Achievement High Scores
Bug	Major	Resolved	There are some levels in which even after we reach 100%, it doesnt show the level completed message
Bug	Major	Resolved	odd intermediate values displayed during level loading
Bug	Major	Resolved	unable to restart a level from the beginning
Bug	Trivial	Resolved	[Common][Levels] Marker must display in front of the Level Number
Bug	Major	Resolved	Tutorial button sometimes not shown on home page
Bug	Trivial	Resolved	volume icon is too small on home page
Bug	Major	Resolved	no need to show High Scores and Score Improvements sections on home page
Bug	Trivial	Resolved	spelling and text size should be changed
Bug	Major	Resolved	Achievement text is not seen well
Bug	Major	Resolved	see negative number for the "Constraints Solved"
Bug	Trivial	Resolved	[Common] Graphic overlap with the Tool Tip
Bug	Trivial	Resolved	[Common] Tool Tip still remains even the Tool bar is gone
Bug	Major	Resolved	cannot exit at the beginning of the tutorial
Bug	Major	Resolved	cannot finish tutorial
Bug	Minor	Resolved	Closing help dialog with [x] button does not work
Bug	Minor	Resolved	Maximum call stack size exceeded
Bug	Trivial	Resolved	[Common] Info boxes must center align with the screen area
Bug	Trivial	Resolved	[Common] 'Enhance Energy' Tool tip displayed most of the time
Bug	Major	Resolved	[Common] Very difficult to play the game in Chrome
Bug	Major	Resolved	patterns appears hidden

Issue Type	Priority	Status	Summary
Bug	Trivial	Resolved	[Common] Top Menu's partly hidden even in Full screen in Chrome
Bug	Major	Resolved	Hint doesn't disappear
Bug	Trivial	Resolved	[Common] Error while playing the game
Bug	Trivial	Resolved	[Common] Error displayed while clicking Menu when playing
Bug	Major	Resolved	Tools Up/Down button does not have any effect
Bug	Trivial	Resolved	[Common] Award Images not displayed
Bug	Minor	Resolved	Close button doesn't work
Bug	Trivial	Resolved	[Common] 'Anount' must --> Amount
Bug	Trivial	Resolved	[Common][Levels] When User set a high Score [If there is no Other High Scores] It won't update the 'High Scores' section
Bug	Trivial	Resolved	[Common][Levels] Over 100% values displayed when loading
Bug	Minor	Resolved	[Common][Levels] High Scores updated but it is not updated in the Game section
Bug	Major	Resolved	Volume button should not be seen in menu screen. Sometimes it appears
Bug	Trivial	Resolved	[Common][Levels] Layout Issue in the Play/Pause Music Button
Bug	Major	Resolved	the screen has grids while zoom in/out
Bug	Major	Resolved	Game stuck
Bug	Trivial	Resolved	[Common] Error occurs while playing the tutorials
Bug	Trivial	Resolved	Top Part (Username, Energy, Pattern and Size) is not clearly visible in normal mode
Bug	Minor	Resolved	paintbrush should not be shown if we click the "Next Level" button
Bug	Major	Resolved	[Common][Levels] If we don't press NEXT from pop up, can't go to next level
Bug	Minor	Resolved	[Tutorials] Mini Map location instruction Issue
Bug	Minor	Resolved	[Tutorials] Text overlap with the Buttons
Bug	Minor	Resolved	[Tutorials] Zoom In/Out are not working
Bug	Minor	Resolved	"Ghost filter" is applied
Bug	Trivial	Resolved	Empty chat msgs also gets posted
Bug	Minor	Resolved	Game is fully accessed by web toolkit
Bug	Major	Resolved	Particles disappears and score goes to 0
Bug	Major	Resolved	Clicking the completed mission shows information for another mission
Bug	Major	Resolved	Game was frozen
Bug	Major	Resolved	Some functionalities are not explained anywhere - e.g. Utility Balance and Purity
Bug	Major	Resolved	Redirection after I pasted http://binaryfission.verigames.com/
Bug	Minor	Resolved	Color of some cells are strange
Bug	Trivial	Resolved	[Common] Score Card displays when we go to Game page
Bug	Major	Resolved	Limit chat input
Bug	Trivial	Resolved	[Common] Text Issue in FF
Bug	Trivial	Resolved	[Common] Layout issue in Top Scores section in FF
Bug	Trivial	Resolved	[Common] Layout issue in Borders of Puzzles in FF
Bug	Major	Resolved	playing a specific level in Puzzles section is loading slowly
Bug	Trivial	Resolved	volume control button is not necessary in the Lobby page

Issue Type	Priority	Status	Summary
Bug	Trivial	Resolved	content should be changed in the Puzzles section
Bug	Minor	Resolved	better add a X button for the modal
Bug	Major	Resolved	Chat area should show timestamp
Bug	Major	Resolved	user info(level and points) is not updated instantly on the Lobby page
Bug	Trivial	Resolved	[Common] 'Record Holder' section Layout Issue in IE11
Bug	Trivial	Resolved	lvl should be changed
Bug	Trivial	Resolved	last two lines should have more vertical distance
Bug	Trivial	Resolved	spelling in the basic info area should be adjusted
Bug	Minor	Resolved	CHat Window Layout issue in IE11
Bug	Major	Resolved	the value of "Number of Solutions Found" is not increased after replaying the level
Bug	Major	Resolved	capitalization should be consistent on the scorecard
Bug	Minor	Resolved	should show basic user info on the level playing page
Bug	Major	Resolved	"Skip" is working slowly
Bug	Minor	Resolved	There is no indication to the user once the puzzle is solved
Bug	Trivial	Resolved	Level 20 description overlaps next line
Bug	Major	Resolved	Multiple Levels Loading Simultaneously
Bug	Major	Resolved	One Circle is overlapping with the other one at the end
Bug	Major	Resolved	f(x)-balance doesn't show permanently sometimes
Bug	Trivial	Resolved	extra dot in the sentence should be removed
Bug	Major	Resolved	should not allow send empty message
Bug	Trivial	Resolved	Can Insert Empty messages
Bug	Major	Resolved	long value cannot be show fully (should restrict the max limit of the text)
Bug	Trivial	Resolved	Chat message display delay
Bug	Trivial	Resolved	Horizontal Scroll bars appears in the Puzzles area
Bug	Trivial	Resolved	'Score' goes beyond the container area
Bug	Minor	Resolved	Close button layout issue
Bug	Minor	Resolved	'Score' Overlap with the bottom border
Bug	Trivial	Resolved	[Cassiopeia][Delta Cassiopeiae] Error Occurred while playing the game
Bug	Minor	Resolved	[Aquila][Gamma Aquilae] Can't complete the Level
Bug	Minor	Resolved	[Aquila][Alpha Aquilae] Can't complete the Level
Bug	Trivial	Resolved	[Pavo][Alpha Pavonis] Can't complete the Level
Bug	Major	Resolved	Alpha Phoenicis - Game crashed when playing this level
Bug	Minor	Resolved	[Cassiopeia][Delta Cassiopeiae] Error Occurred while Restarting the game
Bug	Major	Resolved	[Pavo][Beta Pavonis] Can't complete the Level
Bug	Major	Resolved	Levels with lot of planets can never be completed because of the fact that there are n number of invaders appearing all at once
Bug	Major	Resolved	History is not displayed if user is playing the same level for the second time, however it checks for duplicates and shows appropriate message
Bug	Major	Resolved	Sometimes invaders are not appearing but only bursting-animation is shown
Bug	Major	Resolved	Error while playing Alpha Pavonis

Issue Type	Priority	Status	Summary
Bug	Major	Resolved	Beta Aquilae - Not able to complete this level. Tried all combinations of the Rift nodes
Bug	Major	Resolved	IDEA tool appears on the planets screen when we exit out of the game
Bug	Major	Resolved	Alpha Circini after first rift sealed
Bug	Major	Resolved	unable to select any section
Bug	Major	Resolved	tried sections not played
Bug	Major	Resolved	[Something that doesn't make sense] - Meaning of the "Bar with a moving arrow" in the game-play area is not understandable
Bug	Major	Resolved	Delta Circini - Bounty is not reset when the level is restarted
Bug	Major	Resolved	Game disappeared and a blank white screen came up when playing
Bug	Major	Resolved	Delta Circini - Not able to set the Rift to a particular path. It keeps on resetting to another path.
Bug	Major	Resolved	[Something that doesn't make sense] - After completing a level, user has to manually exit the current level to move on to next level
Bug	Major	Resolved	Gamma Cassiopeiae - "Cannot read property getTraceOutEdge" Error displayed after zapping an invader
Bug	Major	Resolved	Level is marked as complete though player has failed the level
Bug	Trivial	Resolved	[Serpens][Alpha Serpens] I.D.E.A Section is not displayed
Bug	Major	Resolved	Game level name goes outside the planet boundary
Bug	Major	Resolved	Game level name overlaps with the Planet name
Bug	Major	Resolved	Showing all og the levels inside Centaurus as complete
Bug	Minor	Resolved	Dragging the map to the rightmost screen causes the page to expand.
Bug	Major	Resolved	Delta Circini - Not able to complete this level though I have tried almost every part of the Rift (more than 20 attempts)
Bug	Major	Resolved	Information message displayed during the game-play does not get cleared even when the user is in map
Bug	Minor	Resolved	[Cassiopeia][Alpha Cassiopeiae] Clicking on 'UNLOCK ALL' won't clear the Crossed Paths
Bug	Major	Resolved	Incorrect Credit is shown when the level is restarted
Bug	Major	Resolved	[Cassiopeia][Delta Cassiopeiae] Clicking on 'Auto Pilot' will Exit the Level
Bug	Major	Resolved	Unable to play
Bug	Minor	Resolved	[Common] Opening the game begins at the tutorial even if the tutorial is completed
Bug	Major	Resolved	[Cassiopeia][Beta Cassiopeiae] Blank Black Area displayed at the bottom when we complete the Level
Bug	Minor	Resolved	[Cassiopeia][Beta Cassiopeiae] Error Occurred while playing the game
Bug	Minor	Resolved	[Common][Tutorial][Sectors] Return to Main Menu Tool Tip Issue
Bug	Minor	Resolved	[Common][Tutorial] After completing a Tutorial; Is won't display as Completed
Bug	Trivial	Resolved	unnecessary tooltip should be removed for "Click for Next Level"
Bug	Trivial	Resolved	"Zoom In / Zoom Out" should be "ZOOM IN / ZOOM OUT"
Bug	Major	Resolved	Instead of closing IDEA moves down
Bug	Major	Resolved	Window position-IDEA and game overlay doesn't fit well - screen resolution
Bug	Trivial	Resolved	[Common][Tutorial] Sealing : Text go beyond the container area
Bug	Minor	Resolved	[Common] Content overlap when we move the graph in Rift Node chart
Bug	Minor	Resolved	[Common] Click on I.D.E.A Title section will move the pop up down

Issue Type	Priority	Status	Summary
Bug	Trivial	Resolved	[Common] Blank space displayed
Bug	Major	Resolved	[Common] can't Play the game in IE
Bug	Trivial	Resolved	'Zoom Out' Tool Tip issue
Bug	Minor	Resolved	Nothing happens when we click on 'Combat' button
Bug	Trivial	Resolved	Sometimes Tutorial names overlap with the 'Title'
Bug	Trivial	Resolved	'Unlock positions of all nodes' Tool Tip won't clearly displayed
Bug	Trivial	Resolved	Exit to Main page won't work properly
Bug	Trivial	Resolved	Help Tool Tip overlap each other
Bug	Major	Resolved	Design Contest Badges
Copilot Payment	Major	Resolved	CSFV-4468 Copilot payment
Bug	Major	Resolved	Badges Profile Popup and Forums Fix
Copilot Payment	Major	Resolved	CSFV-4470 Review + Copilot Payment
Bug	Minor	Resolved	Things go out of frame in 'Else' part
Bug	Trivial	Resolved	Tutorial Player progress Bar is not completed
Bug	Trivial	Resolved	Duplicate Freebies detected
Bug	Trivial	Resolved	All the objects are not displayed in the Freebies
Bug	Trivial	Resolved	[common] Extra Credit button is not working
Bug	Major	Resolved	When user add 'CROSS ROADS' it won't appear in the game preview
Bug	Major	Resolved	Bad request - 400 encountered
Bug	Major	Resolved	Flip function is not working properly
Bug	Major	Resolved	freebies section should not have duplicate items
Bug	Trivial	Resolved	All the objects are not displayed in the Popup box
Bug	Trivial	Resolved	Some items are not fully displayed
Bug	Major	Resolved	Sometimes theres nothing in the bottom gate
Bug	Major	Resolved	Previous Stash Icons displayed when we come again
Bug	Minor	Resolved	When user add 'CROSS ROADS' it won't appear in the game preview
Bug	Major	Resolved	Even after i unlock the monster hatchery it is not enabled
Bug	Major	Resolved	Can't complete the Forest Loop Level
Bug	Trivial	Resolved	Monster Hatchery is not activated
Bug	Major	Resolved	Create unlimited freebies
Bug	Major	Resolved	freebies section should be able to be expanded larger
Bug	Major	Resolved	Nothing happens on clicking on Take Class
Bug	Major	Resolved	Although logged in one of the screen displays guest
Bug	Major	Resolved	Last two Levels (Tutorials) completed automatically; (PR327, PR333)
Bug	Minor	Resolved	PR120 video is not playing
Bug	Trivial	Resolved	[common] Grade-D must display in single line
Bug	Major	Resolved	PR301: Required Course is wrong
Bug	Major	Resolved	PR330: Required Course is wrong
Bug	Major	Resolved	Take Class is not working

Issue Type	Priority	Status	Summary
Bug	Major	Resolved	the values should be 0 when there is no Music/Fx

Appendix B.   Expert Game Analysis: Dynamakr

B.1   Quick Summary

B.1.1   Best Features

- Graphics look cool and the story/setting seems intriguing.
- The shooter game is fun.

B.1.2   Needs Improvement

- Need to give the 50,000 ft view first: A single, clear goal with steps to achieve it like "Enter the dynamo by filling up one of the green bars at the top."
    - Later you can get more nuanced with ideas like "you want to get as much energy as possible" and "linked nodes produce more energy."
    - This also applies to the weaver – a single clear goal like "shoot everything in sight" should be the first thing you tell the player.
- Terminology does not aid understanding. Terms like pattern, knot, and snarl don't seem to correspond to any of the game graphics.
- Lots of movement and lots of clicking to achieve goals. The patterns move constantly, which makes it a struggle to use the interface.
- There seems to be a very weak connection between what the player does and what happens with the patterns on screen. It is very difficult to predict what will happen with any given action, making the game mechanics very difficult to learn.

Table 7 shows a description of each area for analysis and its priority for the Dynamakr game. Each of these areas are addressed in the following sections.

Table 7 Areas of Analysis and Priorities for the Dynamakr Game

Area	Priority
Usability questions: Heuristics	
Visibility of system status	High
Match between the system and the real world	High
User control and freedom	Low
Consistency and standards	High
Error prevention	Medium
Recognition rather than recall	Low
Flexibility and efficiency of use	Low
Aesthetic and minimalist design	Low
Help users recognize, diagnose, and recover from errors	Medium
Help and documentation	Low
Game questions	
Tutorial analysis	High
Engagement analysis	Medium
Coherency analysis	Medium
Analysis of value to player provided by game	Medium

B.2 Usability Questions: Heuristics Analysis

B.2.1 Visibility of System Status
The game should keep players informed about what is going on, through appropriate feedback within reasonable time. What feedback is missing?

- It is unclear what the semi-circular energy-bar line (energy points?) around each pattern represents and how it is changed.
- It is unclear why there is a green number to the right of the green radiating hexagons.
- It is unclear why some patterns have white stars.
- It is unclear what the various colors of squiggly lines indicate.

B.2.2 Match between the System and the Real World
The game should speak the player's language, with words, phrases, and concepts familiar to the player, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order. What terms are out of place or poorly aligned with what they represent?

- The color red has a negative connotation that can cause players to think that there is something wrong with the patterns, even though a pattern might be as optimized as possible.
- The graphics do not necessarily match the language, such as snarls, knots, etc. It is also unclear how snarls and knots get created or undone in the game (other than shooting them).
- There seems to be a very weak connection between what the player does and what happens with the patterns on screen. It is very difficult to predict what will happen with any given action, making the game mechanics very difficult to learn.

B.2.3 User Control and Freedom
Players often choose actions by mistake and need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo. What mistakes require too much work to recover from?

- There is no undo button to go back to a previous step. Even if there is no benefit to undoing a completed step from a score perspective, there might still be value in undoing the automatic pattern rearrangement.
- Constant automatic shuffling and rearranging the patterns is very disorienting and decreases a player's sense of control. It also confuses players and makes the game feel arbitrary.

B.2.4 Consistency and Standards
Players should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions. What inconsistencies make playing or understanding the game harder?

- The game's mechanics are unclear to the point that the game can seem chaotic, much like a kaleidoscope. Sometimes it seems that adding a new pattern one time may cause the entire screen to rearrange itself to the left, but rearrange itself to the right on the next addition. It is very difficult to learn the rules when it is difficult to identify the consistent behaviors.
- The game's story refers to a quantum 3D printer, but then seems to ignore this central aspect of the game.

B.2.5 Error Prevention
Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and

present players with a confirmation option before they commit to the action. Does the game let me blunder into serious errors?

- May not be applicable in the pattern portion of the game.
- In the shooting part of the game, it is difficult to identify power-ups or distinguish them from enemies. It is too easy to lose a powered up weapon when the player accidentally picks up a low-level weapon. Consider adding the option to let users reject an unwanted weapon.

B.2.6 Recognition instead of Recall
Minimize the player's memory load by making objects, actions, and options visible. The player should not have to remember information from one part of the game to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate. Which instructions are difficult to find or refer to?

- The graphical presentation does not require players to recall vital information to play.

B.2.7 Flexibility and Efficiency of Use
Accelerators—unseen by the novice player—may speed up the interaction for the expert player such that the game can cater to both inexperienced and experienced players. Allow players to tailor frequent actions. What actions do I find repetitive or wish I could hotkey/macro?

- Consider adding hotkeys for the various pattern tools.
- Consider adding the ability for players to change weapons during the shooting portion.

B.2.8 Aesthetic and Minimalist Design
Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. What can be removed to improve clarity?

- The rotating ring around each pattern draws more attention than the semi-circle around it. If the semi-circle contains important data, it should be more salient than the rotating ring.
- The jittering lines can become very distracting.

B.2.9 Help Users Recognize, Diagnose, and Recover from Errors
Error or failure messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. When I fail or make a mistake, do I understand why and how to do better?

- The game mechanics, including errors, are difficult to discover, which makes it difficult to learn how to improve.

B.2.10 Help and Documentation
Even though it is better if the game can be used without documentation, it may be necessary to provide help and documentation. This information should be easy to search, list concrete steps to be carried out, and not be too large. What things do I wish I could look up quickly while playing?

- It is great that there is a help button in the bottom right corner; unfortunately, the documentation provides only limited support to the player trying to understand the complexities of this game.

B.3   Game Questions
B.3.1   Tutorial Analysis
Assessment of the effectiveness of the tutorial; how effective it is at teaching its topics, how well you feel you understand the game at the end of it, how well it sets you up for the jump to real gameplay, how well it draws you into the game. Did the tutorial help? What kind of player does it support? Would you finish it?

- Tutorial throws out a lot of jargon that is tough to understand. Even where the main ideas come through, it is not clear whether the player should enter the dynamo as soon as possible or wait a bit, or how to make that decision if it's a trade-off. None of the effects of actions are clear (beyond creating new patterns and marking them with the tools like the energizer).
- Need to start the player off with a simple, clear goal and then add nuance afterwards.
- The tutorial doesn't explain the connection between the two games or any strategy tips or information. The help pop-ups are useful and mention that connected patterns are worth more energy, but this seems like something that should be more explicitly taught, since it's key to differentiating the actions available.

B.3.2   Engagement Analysis
Assessment of overall enjoyment, including: what elements make the game enjoyable, what elements detract. How can elements be changed to enhance enjoyment?

- The main thing that has potential for a fun game loop is the ability to seed a level with goodies and then go in and collect them.
  - This would be more compelling and apparent, though, if there was some count or weight or whatever attributed to actions in the pattern-finding game. For example, a snarl danger level might be shown on the screen and energizing a pattern would reduce it immediately
  - To close this loop, there needs to be something to spend the collected loot on once the player exits. This could be as simple as purchasing further customization options, like seeding in weapons and shields by spending energy to add them prior to entering the weaver.

B.3.3   Coherency Analysis
Assessment of coherency and balance between elements, such as: mechanics, story, aesthetics, and technology. What elements seem to conflict or undermine each other?

- The lack of clear connection between the games (from the player's perspective) prevents that from being a strength. Some rewording to help the player fit the two games together conceptually and some more transparency of the mechanics connecting them would go a long way here.
- All the motion, animation, and flying/zapping bits in the pattern-finding game seem to undermine the ability to do anything with it. That, plus the unclear connections to the other game make this feel a bit like a cool data visualization instead of a game.

B.3.4   Analysis of Value to Player Provided by Game
What is the player getting out of playing the game? Why would they press the "next level" button? Is it fun? Are they making progress? Are they leveling up or filling a bar or something? Are their game-playing peers depending on them?

- There is little progression of the experience—the bars get larger, but it would be more compelling if this was tied to discrete "level-up" events that the player could see coming, such as "next level at: 10,000 XP"

- It would also help if more tools and/or powerups were unlocked or if there was a sort of "energy multiplier" or some other signifier of progress
- There is no tie to any extrinsic motivation, for example:
  - Indications of overall progress being made (this could be the energy multiplier, if it's true that more passes by anyone tend to increase the energy of moves)
  - Leaderboards or other forms of comparison to other players
  - Benchmarks of any sort to let the player know whether or not they did well at a level. "You got 3750!" is less compelling than "You got 3750 out of a possible 5000!"

Appendix C.   Expert Game Analysis: Binary Fission

C.1   Quick Summary

C.1.1   Best Features

- Very playable, satisfying game of splitting things up
- The graphics are appealing

C.1.2   Needs Improvement

- There is little connection at the moment to any motivational loop – it is fun to do for a bit, but what brings me back?
- Unfinished pieces like algorithms, power rings, end of tutorial

Table 8 shows a description of each area for analysis and its priority for the Binary Fission game. Each of these areas are addressed in the following sections.

Table 8 Areas of Analysis and Priorities for the Binary Fission Game

Area	Priority
Usability questions: Heuristics analysis	
Visibility of system status	High
Match between the system and the real world	Medium
User control and freedom	Low
Consistency and standards	High
Error prevention	Low
Recognition rather than recall	Low
Flexibility and efficiency of use	High
Aesthetic and minimalist design	Low
Help users recognize, diagnose, and recover from errors	Low
Help and documentation	Medium
Game questions	
Tutorial analysis	Medium
Engagement analysis	Medium
Coherency analysis	Medium
Analysis of value to player provided by game	High

C.2   Usability Questions: Heuristics Analysis

C.2.1   Visibility of System Status

The game should keep players informed about what is going on, through appropriate feedback within reasonable time. What feedback is missing?

- There is no connection between a ring option and the effect in the nucleus, other than that certain colors are more effective at separating quarks.
  - There is a one-to-many mapping, where the same filter option icon could cause the quarks to separate in very different ways. This makes it impossible to learn or predict the behavior of each filter option type, requiring the player to review each of the options.
  - Every time a player clicks on and off of a nucleus, they are presented with a new set of options.

- For players to learn the game mechanics and behaviors, there must be a strong correlation between cause and effect.
- The difference between "levels" and "tutorials" was unclear. At what point does the player transition from one "level" to another versus move on to the next "tutorial?" Consider explaining the difference or at least marking the transition by using a different background (or other visual or auditory cue) to provide a sense of progression.

C.2.2 Match between the System and the Real World

The game should speak the player's language, with words, phrases and concepts familiar to the player, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order. What terms are out of place or poorly aligned with what they represent?

- The scoring mechanism is too opaque; there does not seem to be a strong correlation between the filter options chosen and the number of points scored. Would the score ever reflect the fact that a solution might require a player to select a non-pink filter option? Is it always best to select the pink filters (if so, why bother providing players with other options)?

C.2.3 User Control and Freedom

Players often choose actions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo. What mistakes require too much work to recover from?

- Going back a step (to a previous nucleus) to try a new approach is a very helpful ability; however, if a user decides to undo their undo and go back to their original option, the player is presented with completely new quark filter options (which may not include the desired original option).

C.2.4 Consistency and Standards

Players should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions. What inconsistencies make playing or understanding the game harder?

- Quark filter options are not presented in a consistent manner. Every time a user clicks on the nucleus, they are provided with a different filter option set.

C.2.5 Error Prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present players with a confirmation option before they commit to the action. Does the game let me blunder into serious errors?

- Did not seem to be any issues during the evaluation.

C.2.6 Recognition rather than Recall

Minimize the player's memory load by making objects, actions, and options visible. The player should not have to remember information from one part of the game to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate. Which instructions are difficult to find or refer to?

- The game does a good job of simplifying the mechanic of dividing/separating quarks, which prevents the player from having to remember any critical information.

C.2.7 Flexibility and Efficiency of Use

Accelerators—unseen by the novice player—may often speed up the interaction for the expert player so that the game can cater to both inexperienced and experienced players. Allow players to tailor frequent actions. What actions do I find repetitive or wish I could hotkey/macro?

- The manner in which quark filter options are presented requires an unnecessary degree of coordination to cycle though them.
  - The size of the filter options requires more precision than necessary. Making the target sizes bigger would alleviate the precision requirement (see Fitts's Law).
  - People are more effective at using a mouse to move in straight lines. The circular option presentation format requires users to move the mouse in a circular motion, which requires amore precision and time than a linear format. If a circular presentation ring is an essential design choice, then consider making the option ring larger with larger targets. If the ring is not essential, please consider a linear presentation format.
  - Please consider allowing the user to cycle though the options with the arrow keys.

C.2.8 Aesthetic and Minimalist Design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. What can be removed to improve clarity?

- The game was not overloaded with distracting graphical elements. For the most part, every graphical element had a purpose; it struck a decent balance with the data-ink ratio.

C.2.9 Help Users Recognize, Diagnose, and Recover from Errors

Error or failure messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. When I fail or make a mistake, do I understand why and how to do better?

- There did not seem to be any situations where a player would be unable to recover from a mistake or error, other than when a desired filter option disappears from the ring when the player accidentally clicked off of it and receives a new filter ring.

C.2.10 Help and Documentation

Even though it is better if the game can be used without documentation, it may be necessary to provide help and documentation. This information should be easy to search, list concrete steps to be carried out, and not be too large. What things do I wish I could look up quickly while playing?

- There did not appear to be any mechanism for viewing help documents and materials. Although this game is "simple," a user guide might prove useful to explain any advanced techniques.

C.3 Game Questions

C.3.1 Tutorial Analysis

Assessment of the effectiveness of the tutorial; how effective it is at teaching its topics, how well you feel you understand the game at the end of it, how well it sets you up for the jump to real gameplay, how well it draws you into the game. Did the tutorial help? What kind of player does it support? Would you finish it?

- The tutorial explains the concepts well, and lets the player get some experience with them.
- The explanation of why you might sometimes want to take a filter that isn't the brightest is not very clear; it would be more helpful to explicitly explain it.

- This is also true of the filter cap, which doesn't seem to be explained.

C.3.2 Engagement Analysis

Assessment of overall enjoyment, including: what elements make the game enjoyable, what elements detract. How can elements be changed to enhance enjoyment?

- It is satisfying to play when you are solving the puzzles, but eventually gets repetitive. The unlocks should help this once implemented, as would a progression of difficulty (or at least size) in the puzzles.
  - Need to be sure that the unlocks are more spaced out, though; right now it seems like there's a level-up after each level and that means a really quick pace through the unlocks.

C.3.3 Coherency Analysis

Assessment of coherency and balance between elements, such as: mechanics, story, aesthetics, and technology. What elements seem to conflict or undermine each other?

- The name, aesthetics, avatar pictures, and game mechanics all work really well to reinforce each other.
- The filter coloring should convey more information than it seems to. If there are times where it is good to split into two groups with mixed colors and other times where it is good to split off as many of one color as possible, then the best use of colors would be to communicate:
  - Is this making 0, 1, or 2 mixed-color piles?
  - Is this filter making the best split of its type among the filters shown? That is, dividing the most evenly if both piles are mixed color vs. separating out the largest single-color pile if there's only 1 mixed pile.

C.3.4 Analysis of Value to Player Provided by Game

What is the player getting out of playing the game? Why would they press the "next level" button? Is it fun? Are they making progress? Are they leveling up or filling a bar or something? Are their game-playing peers depending on them?

- The intrinsic value of the puzzle-solving is good. A solid unlock system and a progression of puzzle size/difficulty/complexity/etc. would enhance it even more.
- There doesn't seem to be any hooks for extrinsic motivation, such as leaderboards, the overall progress that all players are contributing to, etc. The "best" benchmark would at least help them judge their own solutions (once there are others to compare to), but some indication of overall progress both individually and for the whole group would seem important to the players you're looking to attract.

Appendix D.　　Expert Game Analysis: Monsterproof

D.1　Quick Summary

D.1.1　Best Features

- The graphics, humor, and progression are all quite engaging and solving a puzzle is satisfying.
- The theme mostly enhances understanding of the game and provides a good framework to explain the very complex topic.
- Setting the user up to expect a game based on logic puzzles right from the start makes it easier to get into the game and understand the motivation.

D.1.2　Needs Improvement

- The interface has several clunky parts that require extra clicks to accomplish frequently repeated tasks and doesn't always give you a good sense of where you are or what you're about to change.
- The complexity ramps up quickly. Even though the tutorials explain well, moving directly on to the next tutorial means that the player quickly forgets old lessons or never truly grasps the concepts being taught. Each coherent group of tutorials really needs some form of "homework" that follows up so the player can practice what was learned. Like "ok, now you try – go gather 3000 stones."

Table 9 Areas of Analysis and Priorities for the Monsterproof Game

Area	Priority
Usability questions: Heuristics analysis	
Visibility of system status	Medium
Match between the system and the real world	Medium
User control and freedom	Medium
Consistency and standards	Medium
Error prevention	High
Recognition rather than recall	High
Flexibility and efficiency of use	High
Aesthetic and minimalist design	Low
Help users recognize, diagnose, and recover from errors	Low
Help and documentation	Low
Game questions	
Tutorial analysis	High
Engagement analysis	Low
Coherency analysis	Low
Analysis of value to player provided by game	High

D.2　Usability Questions: Heuristics Analysis

D.2.1　Visibility of System Status

The game should keep players informed about what is going on, through appropriate feedback within reasonable time. What feedback is missing?

- The cards for operations are often difficult to parse. In particular, the operation symbols could be significantly larger, or could enlarge when they are selected.

- The visual cue for which scene you are working on and which ones are locked or need fixing (the little icons on the buildings along the path) is subtle and can be easy to miss. It is also unclear which of those icons corresponds to your current location.
- The bets interface is quite hidden—you can place a bet, but you can't see whether or not you've placed one, you can't check up on your previous bets to see their status, and the messages for winning or losing a bet don't give you a good sense of what you bet on. It would also be nice to go back to a level once you've been told your bet failed.

D.2.2   Match between the System and the Real World

The game should speak the player's language, with words, phrases and concepts familiar to the player, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order. What terms are out of place or poorly aligned with what they represent?

- The analogy of the gates and the idea of keeping monsters out have been changed, so the idea that you are "monsterproofing" the area (especially given that you are portrayed as a monster yourself) doesn't seem to jibe. This has a couple of consequences:
  - "Open Sesame" as the submit action and "gates," both the term and the artwork, don't really make sense to the player. Instead, potentially just mention that the gates being open lets you know the road is accessible or something similar.
  - With the focus being on creating roads (which makes sense mechanically), it seems like the icons for accessing the different sections of a level should be directly on a road piece. This would mean creating a road piece that went "through" the forest in some sense (from the forest icon to the gold mine icon on the most simple forest levels). On the plus side, these would be easier to see.
- Could the activity be reframed to explicitly be about getting the teams of monsters from each site to cooperate on building a road? Then "open sesame" can just be "build road," and it now makes sense that you are trying to "say the same thing" but in terms that the monsters at both sites understand. It even lends itself to the day-shift/night-shift analogy in the forest (it's harder to build roads through forest or something similar).
- Score seems like a thing I want a lot of. Most games in which you are trying to get less "score" tend to call it something else, like "strokes" or "moves" or whatever. Would "cost" or "parts" or something like that work? Cost or something similar would also make "freebies" very clear.
- A minor thing, but Mon Academy can just be Academy, in the same way that the quarry and the sawmill just use familiar words.

D.2.3   User Control and Freedom

Players often choose actions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo. What mistakes require too much work to recover from?

- Undo is crucial—it is often difficult to drag or remove the exact piece you want and it is easy to do something that is then difficult to manually undo.
- A reset or clear button to set you back to the original state is needed, especially on levels where you can modify top and bottom.
- A save/load capability is needed so that you can return to a puzzle later (not just when you leave for the day, but also if you want to try something else for a bit, or just go out and sell some resources so you can bet big on the puzzle being unsolvable).

D.2.4 Consistency and Standards

Players should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions. What inconsistencies make playing or understanding the game harder?

- The drag and drop interface is mostly intuitive, but the card-based backing system is not. Despite the instructions in the tutorial, the inclination when trying to form "snake less than or equal to dragon" is to drag the snake onto the field, then build the other pieces off of it, left to right, like you would write it. Starting with snake less than or equal to fairy, then replacing fairy with dragon seems like an odd way to go about it, even if it is fewer steps.

- Score only seems to count on the last step, which creates an inconsistency in the rule about whether or not to prefer freebies—basically, if everything is free in the earlier sections, then I should be willing to make stuff complex to leverage freebies and simplify the last step as much as possible. Perhaps that's desirable behavior, but it seems inconsistent/exploitative.

- Why does adding or subtracting a number require me to double-click and then choose "add/subtract zero," but multiplying or dividing means dragging a new card in from the quill menu? Seems like I should just be able to choose a single menu item to add an operator and a different menu item to swap an operator to something else.
  - This could be done with a single on-screen location with a "plus zero" icon that could be swapped to "minus zero" or "divide by 1" or "multiply by 1," etc.

- The tray for freebies looks more like a visual element than a tray—there should be more of a cue that it is a workspace for things to be dragged to (like the two on the left).

- Dragging a card (such as a piece of an equation) from the panels on the left allows you to treat that card like a monster (substitute it in, or add to both sides, etc.), but you can't do this with freebies or their subsections.

- It's odd that I can drag a monster onto a slot and then choose "plus zero."

D.2.5 Error Prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present players with a confirmation option before they commit to the action. Does the game let me blunder into serious errors?

- It is fairly easy to blunder into bad situations because the consequences of interface actions are not always clear, and because there is no undo (perhaps some of these are due to bugs):
  - Problems seem to occur when accidentally dropping freebies into the wrong place, or dropping monsters or other cards onto freebies, or double-clicking freebies (this might have been fixed in Chrome, since I couldn't reproduce this error; it was reproducible in Firefox though)
  - Dropping a monster onto an operation card can have unexpected results if the whole card is highlighted
  - A confirmation that I'd like to substitute when that's the only option would be more useful if it showed what was being substituted for (like perhaps if the top of the dialog showed the card to be changed or replaced). This is especially true for "remove;" it would be nice to confirm what it is I'm removing and not end up accidentally deleting the whole equation over and over again.

- It would be worth explaining the card-based UI a little more. The highlighting is quite clear once you get it, but not necessarily obvious at the start (and a potential source of frustration if you don't understand why the context menu keeps changing).
- It would be helpful to show a symbol of some sort when the user is hovering over an action that isn't allowed (like if they are about to drop a monster onto the field without adding an equation first, or about to drag a freebie into the main equation, etc.).

D.2.6 Recognition rather than Recall

Minimize the player's memory load by making objects, actions, and options visible. The player should not have to remember information from one part of the game to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate. Which instructions are difficult to find or refer to?

- The video tutorials make it difficult to quickly refer back to instructions, especially if they aren't in the tutorial you are currently working on (or you're on a level beyond the tutorials).
  - Some form of quick reference card for each tutorial would be very helpful. Like showing a "copy-up" play with "Assume the conclusion!" or "Try copy-up!" as the card header.
- This also applies to using the pop-up menu—there is no indication of what you are acting on so you have to remember.
- Collapsed cards can require some of this as well; It's like playing memory when you want to remember what they do, or else you have to scroll around a huge field of them with them all opened (and the equation closes itself when you interact with it).

D.2.7 Flexibility and Efficiency of Use

Accelerators—unseen by the novice player—may speed up the interaction for the expert player so that the game can cater to both inexperienced and experienced players. Allow players to tailor frequent actions. What actions do I find repetitive or wish I could hotkey/macro?

- Most frequent actions: expand all sub-parts of a card, search for a monster, substitute one card for another, add a term to one side, simplify an expression, and remove a term from one side. Negate a term would also be one, but it isn't clear if that can be done beyond using the simplify command.
  - Of these, searching for a monster and simplifying are relatively easy.
  - Substituting one card for another and adding a term to one side have multiple steps that slow them down.
  - Remove a term from one side is difficult and dangerous since you might remove the whole equation (I mostly subbed in the appropriate identity and then simplify.)
  - Expand all sub-parts requires individual clicks to drill down to them; a single command would be better
- The incredible complexity of some of the equations can be overwhelming, especially early on. Creating a system by which a user can substitute a single icon to represent a complex expression everywhere it shows up (like using `HornedBull` instead of `B[Bull[O[HornedSkull->1]]]`) would help simplify the thought process of dealing with a puzzle. It might not always be useful (you might need to understand the guts to find the right freebie), but it could at least help you realize that the simple solutions won't work and find the puzzles where it's necessary to drill down.

- This could also be done automatically to simplify levels for novice users. They might not be able to solve the simpler level (so they could place a bet on that), but it would still keep them from hitting that massive bump up after the tutorial.
- If save and load is implemented, then a notes feature that lets you tell yourself where you were at on a puzzle when you reload would be nice.

D.2.8   Aesthetic and Minimalist Design
Dialogs should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialog competes with the relevant units of information and diminishes their relative visibility. What can be removed to improve clarity?

- This is all much improved with the chests and the easy search for monsters and filtering of the freebies, although the freebies monsters could use their own chest-like groupings of "included in the answer" and "not included in the answer" at the very least (or just sort the list so the ones in the answer are always at the front).
  - Can the chests with 0 in them be removed? If not, can all the chests that don't contain a monster that is currently in the equation be hidden by default (and only shown through a user command)?
- Using the substitution system described above to simplify equations initially (perhaps letting advanced players try to "investigate" a monster and discover its inner details) might make for a cleaner presentation than the list of N monsters that many puzzle equations collapse to.

D.2.9   Help Users Recognize, Diagnose, and Recover from Errors
Error or failure messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. When I fail or make a mistake, do I understand why and how to do better?

- If grabby claws prevent you from winning, they should cause the "Open Sesame" to fail
- Some form of quick compare for the complex expressions would be helpful, like selecting two collapsed cards and having the system check that their guts are the same.
- The idea that a puzzle might not be solvable should be emphasized more to help users that are really struggling find a way out. The bets interface explanation in the tutorial is fine, but easy to forget amongst all the other information and the gavel is not obviously associated with unsolvable levels. There should be some on-screen text or other reminder that when you're frustrated with a level it might be because there actually isn't an answer.
  - Save/load would also help here, since you could just pause and try again later when you are fresh.

D.2.10 Help and Documentation
Even though it is better if the game can be used without documentation, it may be necessary to provide help and documentation. This information should be easy to search, list concrete steps to be carried out, and not be too large. What things do I wish I could look up quickly while playing?

- A list of the key concepts and/or the quick reference cards mentioned above would help.

D.3   Game Questions

D.3.1   Tutorial Analysis
Assessment of the effectiveness of the tutorial; how effective it is at teaching its topics, how well you feel you understand the game at the end of it, how well it sets you up for the jump to

real gameplay, how well it draws you into the game. Did the tutorial help? What kind of player does it support? Would you finish it?

- The videos explain their concepts clearly and are engaging to watch, making the process of learning the basics enjoyable.
  - The clear framing of the game as a logic puzzle right from the start does a great job of setting expectations and helping the user engage with the game.
- Using only videos isn't ideal because they require a lot of attention, memory, and headphones. Some of this would be mitigated if there was more text to help identify what's happening (even very minimalistic text).
  - Some form of tutorial summary reference card that you can access would also be nice, rather than hunting through old tutorials to find an explanation.
- Another drawback to video-based tutorials is that they don't age well, UI, art, etc. that changes in the game doesn't change in the video, so they get stale and potentially misleading or they need to be updated.
- Specific comments on the tutorials:
  - Electives are poorly placed—it seems like they should be in a separate section that can be referred to as needed, or they should be required. It also seems like the elective that unlocks the workshop isn't really optional.
  - Obvious stamps on completed tutorials and a scrollbar showing where you are in the list would make it clearer what you've done and how far you have to go.
  - Sound levels are different for different tutorials—in particular, professor Volron's voice is harder to hear than Joey's.
  - In the section that discusses buying things, it would be better to start the list off with some things that are real and then drop in something that is obviously a joke. As it is, the list of all joke things makes it seem like some of those things are real things you can buy.
- The bump from tutorial to gameplay remains problematic. The elements of a great, smooth transition are there if each new concept (combining an equation with a freebie, modifying an equation to make the next step work, wobbles, forests, each complex operator, grabby claws, etc.) was rolled out with some tutorials followed by maybe three levels that practice it (and perhaps also use previously introduced concepts as needed) before the next concept and its corresponding content are unlocked.
  - Rolling up complications that have not yet been introduced so that the player can't manipulate them would allow this to operate on real levels during the practice sessions, with the potential cost of having unsolvable levels.
  - Alternately, these practice levels could be curated or crafted. While that might produce a longer lead time from when a player starts to when they are solving real levels, players that are overwhelmed by complexity are unlikely to solve anything either.

D.3.2   Engagement Analysis

Assessment of overall enjoyment, including: what elements make the game enjoyable, what elements detract. How can elements be changed to enhance enjoyment?

- Solving a puzzle is very satisfying. Even just being hot on the trail of a possible solution is satisfying.
- Other current detractors:

- Confusion about mechanics, the things represented in equations, and the options for manipulating expressions.
- Bugs encountered:
  - Lots of graphical lag on one of our machines right from the start with a new browser page (so this was not related to a memory leak).
  - Seemed like a level was solved, but Open Sesame didn't work and it wasn't clear why not.
  - Bugs with dragging cards to places they weren't supposed to be (seems like this can still occur if you substitute a single monster for the entire equation).
  - Music during videos is too loud.
  - Could sometimes enter a mode like you were editing a freebie.
  - Making a mistake and having to redo a significant amount of work is a big detractor.
- The unlock tree, the buildings that pay out resources when you return, and the betting mechanic seem like good cross-session engagement factors.

D.3.3   Coherency Analysis

Assessment of coherency and balance between elements, such as: mechanics, story, aesthetics, and technology. What elements seem to conflict or undermine each other?

- The concept of gates you are opening doesn't seem to be supported by the other elements of the story.

D.3.4   Analysis of Value to Player Provided by Game

What is the player getting out of playing the game? Why would they press the "next level" button? Is it fun? Are they making progress? Are they leveling up or filling a bar or something? Are their game-playing peers depending on them?

- The intrinsic value of the puzzle solving is quite good, and the smoother the interface can be (both for the puzzle solving and the betting) the more fun it will be to just sit and work on puzzles.
- There is also some value provided by curiosity at unlocking new buildings though the current display (which doesn't show that there's an unlock tree until you unlock a pre-requisite) and the small number of buildings on the main screen make it clear that there is not much to unlock. This would all be more of a motivation if more of the mechanics were hidden and only unlocked through purchases at the upgrade shop.
- A Daily (Weekly?) Puzzle or something similar would give players more value for returning to play—perhaps with bonus prizes for the first person to solve it or the first N people to solve it. Could make the refresh time known so that competitive players can anticipate it.
- A leaderboard or similar concept for puzzle scores, gold spent/resources gathered, bets won, etc., would also give some of that extrinsic value to doing well at the game.
- Bugged Level? If 1+S <= A[B] as the freebie claims, then asserting that X + A[B]<= QRS should prove that X + 1 + S <= QRS

Figure 7 Monsterproof

Appendix E.   Expert Game Analysis: Paradox

E.1   Quick Summary

E.1.1   Best Features

- The autosolver provides a smoother, more satisfying way to play.
- Painting with the brushes makes for a friendlier method of interacting with the game elements.
- It seems like all the provided levels can actually be solved, which is much more satisfying to the player.

E.1.2   Needs Improvement

- The tutorial is confusing and starts off with many under-the-hood details that aren't needed. It should be reworked to start from the autosolver and only get the other information to the player once they are an expert.
- Terms and symbols are difficult to understand and are inconsistent.
- There needs to be some additional form of reward loop, level-up progress, or other value mechanism to keep players engaged and give them a reason to play.

Table 10 Areas of Analysis and Priorities for the Paradox Game

Area	Priority
Usability questions: Heuristics analysis	
Visibility of system status	Medium
Match between the system and the real world	High
User control and freedom	Low
Consistency and standards	Medium
Error prevention	Low
Recognition rather than recall	Low
Flexibility and efficiency of use	Low
Aesthetic and minimalist design	Medium
Help users recognize, diagnose, and recover from errors	Low
Help and documentation	Medium
Game questions	
Tutorial analysis	High
Engagement analysis	High
Coherency analysis	Medium
Analysis of value to player provided by game	High

E.2   Usability Questions: Heuristics Analysis

E.2.1   Visibility of System Status

The game should keep players informed about what is going on, through appropriate feedback within reasonable time. What feedback is missing?

- Red conflicts are frequently difficult to find on the playing field and mini-map because they are shown behind the blue circles. As I drag, the autosolver brush circles are highlighted yellow. When the autosolver finishes, these circles remain yellow, which makes it seem like they are still being autosolved. It would be more helpful as feedback if they changed to some other color (green?) and stayed that way until the solver starts again (since it is helpful to know where the previously solved region was)

- It is difficult to determine the current zoom level, making it difficult to determine where the player is in relation to the entire puzzle. This problem is exacerbated by the fact that the playing field is redrawn after every magnification change.

E.2.2 Match between the System and the Real World

The game should speak the player's language, with words, phrases and concepts familiar to the player, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order. What terms are out of place or poorly aligned with what they represent?

- The names "para" and "dox" don't mean anything and don't help the player attach ideas or game mechanics to them. I can't even remember which thing is represented by which name without going back to look at the first tutorial. It might be better to use terms like "switch" and "gate."
- "Painting" is a good term for what the user is asked to do, but the big circle and the hex, square, and circle symbols don't immediately convey the idea of a paintbrush so working in a paintbrush graphic to the list of symbols and perhaps to the big circle itself might make this clearer.
- Autosolver is a clear term, but has the downside of conveying the idea that the computer can do this work itself, which immediately brings up the question of why the player is even involved. This is exacerbated by the autosolver limit, which sounds like an arbitrary restriction on your autosolving that is the only thing preventing you from getting the whole answer by just highlighting the whole map. More on this in the gameplay area.
  - It would be better to use terms like a correction brush that you want to use to fix flaws, but which can run out of ink.
- It is difficult for users to develop a model of the game mechanics because of confusing game instructions and loosely coupled feedback loops in the mechanics.

E.2.3 User Control and Freedom

Players often choose actions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo. What mistakes require too much work to recover from?

- Most actions can be undone automatically, but if you try the autosolver on a section and it breaks things more than it helps, it can be a pain to get back to where you were. It would be nice to be able to undo the previous autosolve attempt at least.

E.2.4 Consistency and Standards

Players should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions. What inconsistencies make playing or understanding the game harder?

- In terms of platform conventions, being able to drag the playing area around with the mouse would be very helpful; the arrows keys/mouse to edge of screen are somewhat clunky and dated navigation tools.
  - The zoom levels are also not very granular and somewhat clunky to apply; mousewheel zoom is the expected default here.
- The icons used to represent the different states of the paras don't correspond to the symbols on the brushes that paint them, making it difficult to distinguish how each brush affects the paras.

- The color-coding of the lines between dox and para are inconsistent; sometimes it seems like they are showing whether there's a match or not and sometimes it seems like they are just based on one of the two colors. Would be best if they just showed orange when the endpoints didn't match and gray when they did.
- Some conflicts seemed to be resolved by painting the same area multiple times. This seems inconsistent to the user. Even if this is because the user painted the area in the correct order to resolve the conflict, there can be a sense of inconsistency to the action. The brush is so big and the paras/doxes are so tiny, the player cannot easily see what has happened to differentiate between the correct resolution action and the failed resolution action. The relationship between the large, autosolving brush and the small, numerous para/doxes, makes for an impoverished feedback loop and hinders players from learning the game mechanics and how to prevent new conflicts.

E.2.5 Error Prevention
Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present players with a confirmation option before they commit to the action. Does the game let me blunder into serious errors?

- All of the game states are reachable from each other so serious errors are not truly possible

E.2.6 Recognition rather than Recall
Minimize the player's memory load by making objects, actions, and options visible. The player should not have to remember information from one part of the game to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate. Which instructions are difficult to find or refer to?

- All necessary information is displayed, though the issues with the correspondence between symbols (e.g., brushes) and their meaning make it harder to use.

E.2.7 Flexibility and Efficiency of Use
Accelerators—unseen by the novice player—can speed up the interaction for the expert player so that the game can cater to both inexperienced and experienced players. Allow players to tailor frequent actions. What actions do I find repetitive or wish I could hotkey/macro?

- There are very few standard actions due to the nature of the game.

E.2.8 Aesthetic and Minimalist Design
Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. What can be removed to improve clarity?

- The entire explanation of paras and dox and states and painting states only confuses the player and makes it difficult to understand the goal. More on this in the Tutorial Analysis section.
- The single-state paintbrushes seem like expert-level tools that are best left for a much later unlock.
- For that matter, the actual colors of the nodes and the dox are only needed when you are using a single-state paintbrush.

E.2.9 Help Users Recognize, Diagnose, and Recover from Errors
Error or failure messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. When I fail or make a mistake, do I understand why and how to do better?

- This is a bit of a problem with no great solution because it wouldn't really be possible to explain how to do things correctly with the types of errors that are possible. If you understand how the tools work you know all there is to know about why they fail.

E.2.10 Help and Documentation

Even though it is better if the game can be used without documentation, it may be necessary to provide help and documentation. This information should be easy to search, list concrete steps to be carried out, and not be too large. What things do I wish I could look up quickly while playing?

- Desirable help sections: a list of controls, an explanation of the brushes, an explanation of states and conflicts, maybe tips and tricks for specific situations that occur frequently.
- Users should be able to access instructions, such as an explanation of the states and how conflicts arise and how to remove them.

E.3 Game Questions

E.3.1 Tutorial Analysis

Assessment of the effectiveness of the tutorial; how effective it is at teaching its topics, how well you feel you understand the game at the end of it, how well it sets you up for the jump to real gameplay, how well it draws you into the game. Did the tutorial help? What kind of player does it support? Would you finish it?

- The tutorial leaves the new user quite confused about the mechanics and the goal of the game.
- The tutorial should really lead off with the goal of the game, giving the player some sense of who they are, what they are doing, and why they are doing it. The most important thing to emphasize here is that it is the player's job to direct resources at solving sections most likely to remove the conflicts while saving resources by leaving out the sections that don't need to be included.
- As currently constructed, the tutorial starts off too fiddly and loses players before it is able to hook them and let them build a framework for what they are doing. The analogy that comes to mind is starting off your tutorial for a medieval game by explaining the details of armor class, attack roll, dodging, weapon type, flanking rules, etc., when all the player really needs to know is when to attack and what button to press to do it.
- Suggest reworking the tutorial as follows:
  - Begin with the autosolver but renamed to something that sounds more engaging like "the master brush" or at least more inclusive of the player, like "optimizer."
    - Explain that your goal is to eliminate conflicts by directing the autosolver, then let the player do that by highlighting the entirety of a small level.
  - Then explain the limit (e.g., by saying that ink is limited and it drains out when you paint).
  - Then let the player play with this in a bunch of levels of increasing complexity, gradually upping the limit.
  - Once the player has gotten through some complex levels, unlock a "show states" map mode and explain how conflicts arise when the states are mis-matched and let the player see how on a simple level the autosolver resolves all these conflicts.
  - Then unlock the single-state tools and explain how the player could use them to manually solve or shake up an area to help find the solution. This could even wait until the user is quite experienced.

E.3.2 Engagement Analysis

Assessment of overall enjoyment, including what elements make the game enjoyable and what elements detract. How can elements be changed to enhance enjoyment?

- Painting areas is satisfying and enjoyable when it is working. Making progress towards full completion is also satisfying, even at the very end when I'm trying to just get that last little bit.
- Finding the conflicts is too difficult sometimes, making it harder to play.
- Selecting the proper things can be tough too; zooming in/out and panning is too clunky to play on all but fully zoomed out.
- Strategies are opaque—it would be nice to get some form of reward loop going for succeeding at finding a strategy.

E.3.3 Coherency Analysis

Assessment of coherency and balance between elements, such as mechanics, story, aesthetics, and technology. What elements seem to conflict or undermine each other?

- There is a lack of coherence in the visual representation of the different elements—the dox, the paras, the conflicts, the symbols for the brushes, the autosolver limit, etc.
- There is an overemphasis on the under-the-hood details for a game that is really about managing autosolver tasking.
- There is no clear story or goal to drive the player beyond the idea that levels should be completed—more of a sense of the player's role and how far they've gotten would help bring the elements together.

E.3.4 Analysis of Value to Player Provided by Game

What is the player getting out of playing the game? Why would they press the "next level" button? Is it fun? Are they making progress? Are they leveling up or filling a bar or something? Are their game-playing peers depending on them?

- Definitely need a stronger reward loop; increasing the autosolver limit gives some basic progression, but some additional form of reward is needed for there to be an intrinsic motivation to play.
  - One example might be to have "extra ink" where the player could choose to overfill the brush (increasing the autosolver limit) a certain number of times per level to try to solve a section they are having trouble with. This might cost points and therefore slow the player's unlocking of more extra ink, but it provides a cool strategic ability that the player has an incentive to improve.
- The extrinsic reward loop is also not clear at this point—there's no indication of scientific progress being made or of how the community is doing as a whole, and there's so little introduction or grounding in why it is valuable to be doing this that it's hard to be motivated to play by those factors.

Appendix F. Expert Game Analysis: Ghost Map—Hyperspace

F.1 Quick Summary

F.1.1 Best Features

- Organizing nodes is fun to do, fighting the aliens is a good distraction while rifts are sealing, and the challenge of finding a good spot to seal can be fun as well (when it works!).
- Love the smoky intro voice-over.

F.1.2 Needs Improvement

- Better indications of the potential strength and duration of a seal attempt would help the player learn and optimize strategy.
- Closing the loop on various mechanics so that they feed back into each other would increase the engagement value and the potential for new experiences as the player progresses.

Table 11 Areas of Analysis and Priorities for the Paradox Game

Area	Priority
Usability questions: Heuristics analysis	
Visibility of system status	High
Match between the system and the real world	High
User control and freedom	Low
Consistency and standards	Medium
Error prevention	Low
Recognition rather than recall	Low
Flexibility and efficiency of use	Medium
Aesthetic and minimalist design	Low
Help users recognize, diagnose, and recover from errors	Medium
Help and documentation	Medium
Game questions	
Tutorial analysis	Medium
Engagement analysis	High
Coherency analysis	Low
Analysis of value to player provided by game	High

F.2 Usability Questions: Heuristics Analysis

F.2.1 Visibility of System Status

The game should keep players informed about what is going on, through appropriate feedback within a reasonable time period. What feedback is missing?

- It was unclear why some rift sealing attempts were unsuccessful, despite having followed the instructions.
    - The rift sealing in general would be much clearer if there was a meter showing you some form of relative strength of your attempt. Like a password strength meter, but applying the rules like "include 2 fracture points" and "follow a single energy signature."
        - It could be made clear that even a max strength attempt might fail, and this would help reinforce that idea and avoid frustration when it does.

- It would also help to have a meter that showed a relative estimate of how long the sealing would take. Even if this is only a guess based on number of nodes included, showing the user that adding one node can double or triple the time it takes (or more) would help them make the tradeoffs.
- In both cases, showing the estimates for the current selection before kicking off the sealers would help reinforce the strategies by giving the player positive feedback for successfully finding a good spot, even if that spot turns out not to work.
- The transition to combat mode is unclear—some visual indicator to distinguish combat mode from planning mode would be useful.
- The explosion feedback for aliens multiplying is too similar to the explosion for destroying an alien, making it very confusing what is going on during combat.
- It isn't clear that exiting a level will allow that level to keep calculating.

F.2.2   Match between System and the Real World

The game should speak the player's language, with words, phrases, and concepts familiar to the player, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order. What terms are out of place or poorly aligned with what they represent?

- It isn't clear what the goal of the alien attacks is and therefore what the purpose of defense against them is. If everything is about the rift sealing, more connection between combat and the success of the sealers seems needed.
  - This could operate as a soft cap on the amount of time sealers can be active; eventually you will get overwhelmed if the sealing hasn't succeeded.
  - Could also be a good hook for progression—better weapons, better armor or shields for the sealers, better auto-pilot combat, etc.
- "Planets" seems like an odd term for nodes that can be moved around and that the player is organizing. Perhaps this would be better phrased as a defense grid or hyperspace grid or something, with a bunch of satellites in it that the player can arrange to help seal a rift.
  - The idea of fracture points would also make more sense if it was this grid itself that contained the rift and therefore needed to be fixed.
- Gaining credits for organizing planets seems like an odd concept. This would make more sense if you simply had to organize the nodes before attempting a seal. Since organizing the planets is satisfying and fun, this would be a more interesting pushback than the credit earning.
  - Could have the nodes unlock after a failed seal attempt or when a new rift appears, so that there is also a pushback to encourage the best possible seal attempts.
  - Alternately, this pushback could come from giving the player only a fixed number of rift sealers to deploy, so that they can't have 10 or 20 different star systems cooking at once.
    - Another opportunity for progression here, where the player earns new rift sealers in some way. This could also be a good mechanism to introduce the concept of the autopilot and engaging multiple sealers.

F.2.3   User Control and Freedom

Players often choose actions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo. What mistakes require too much work to recover from?

- It is tedious and repetitive to have to recharge the red bar after a failed rift closure attempt. Consider allowing multiple attempts on the same rift, or incorporating one of the pushbacks discussed above, to make this time into gameplay instead of what seems like tedium.

F.2.4 Consistency and Standards

Players should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions. What inconsistencies make playing or understanding the game harder?

- It was unclear why a planet scan would reveal one enemy, but a second scan on the same planet would sometimes reveal a different enemy situation (e.g., more, less, different locations).
  - Consider showing aliens arriving from off-screen every time they are added.
- Red is typically associated with bad things or with health bars, so it is strange to have the credits bar be red. It is also inconsistent with the graphics for adding credits (the +50 or whatever from organizing planets), which are a more credit-like yellow color.

F.2.5 Error Prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present players with a confirmation option before they commit to the action. Does the game let me blunder into serious errors?

- The meters concept discussed in the Visibility of System Status section would help to keep the player from kicking off too long of a sealing attempt, and to better juggle the time an attempt will take with its potential for success.

F.2.6 Recognition rather than Recall

Minimize the player's memory load by making objects, actions, and options visible. The player should not have to remember information from one part of the game to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate. Which instructions are difficult to find or refer to?

- No issues.

F.2.7 Flexibility and Efficiency of Use

Accelerators—unseen by the novice player–can speed up the interaction for the expert player so that the game can cater to both inexperienced and experienced players. Allow players to tailor frequent actions. What actions do I find repetitive or wish I could hotkey/macro?

- Navigating between the left menu, the map, and the IDEA interfaces requires considerable mouse movement. Please consider integrating keyboard shortcuts and moving some of the information/interactions directly to the map or IDEA graph. For example, it would be more efficient to have the Rift Sealing button located in the IDEA space.

F.2.8 Aesthetic and Minimalist Design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. What can be removed to improve clarity?

- The interface seems like it could be streamlined by combining the various controls into a single, size-constrained location (as opposed to having them spread across the IDEA, left menu, and map). Seek opportunities to create contextual controls from the map area when interacting with the planets or aliens.

F.2.9   Help Users Recognize, Diagnose, and Recover from Errors
Error or failure messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. When I fail or make a mistake, do I understand why and how to do better?

- Although some text accompanies a failed rift-sealing attempt, it is difficult to figure out specifically what is being done incorrectly. Better indication of the relative strength of attempts would help the player learn the best strategies.
- The feedback for killing vs. hurting aliens is a bit confusing and unclear, and the use of both good and bad explosion graphics makes it even harder to parse. Consider using explosions for only good or only bad outcomes and presenting some other visual feedback for the other type of outcome.

F.2.10   Help and Documentation
Even though it is better if the game can be used without documentation, it may be necessary to provide help and documentation. This information should be easy to search, list concrete steps to be carried out, and not be too large. What things do I wish I could look up quickly while playing?

- The help button should provide more information than to label the lock/unlock buttons.

F.3   Game Questions
F.3.1   Tutorial Analysis
Assessment of the effectiveness of the tutorial; how effective it is at teaching its topics, how well you feel you understand the game at the end of it, how well it sets you up for the jump to real gameplay, how well it draws you into the game. Did the tutorial help? What kind of player does it support? Would you finish it?

- The tutorials could be more specific. For example, it was very helpful when a specific planet was identified (e.g., select planet number 5). This type of specification should be used throughout.
- It was unclear how the blue lines in the IDEA connected to the map space. More emphasis on the ability to select one and see its nodes would help clarify this, so perhaps that should be a distinct, required step in a tutorial.

F.3.2   Engagement Analysis
Assessment of overall enjoyment, including: what elements make the game enjoyable, what elements detract. How can elements be changed to enhance enjoyment?

- Although the game mechanics are tied to specific domain elements, there is an opportunity to add variety without affecting the underlying mechanics. For example, by incorporating a variety of enemies and weapon types, the player could experience additional levels of strategy and tactics, but still accomplish the same task behind the scenes.
- Progression mechanics would help tie the individual moments of play to a larger goal and feeling of accomplishment. This could include:
  - Unlocking or purchasing weapon, sensor, or defense upgrades to improve combat.
  - Improving the autopilot/purchasing additional sealers to allow more rifts to be attempted at once or to increase the size of rift that can be tackled.
  - Improving the payoff of successful seals or alien kills through some sort of multiplier.

- Organizing nodes is fun, so some additional emphasis on it, either through requiring it in order to attempt a seal, or through some payoff mechanism from other players (where you market your organized level or something) would increase engagement.

F.3.3 Coherency Analysis

Assessment of coherency and balance between elements, such as mechanics, story, aesthetics, and technology. What elements seem to conflict or undermine each other?

- The mechanics, story, and aesthetics seem to reinforce each other in most ways. There are a few specific issues discussed in the Consistency and Standards section.

### F.3.4 Analysis of Value to Player Provided by Game

What is the player getting out of playing the game? Why would they press the "next level" button? Is it fun? Are they making progress? Are they leveling up or filling a bar or something? Are their game-playing peers depending on them?

- Several of the game elements are entertaining to play with, such as organizing the nodes, finding a good seal attempt, and fighting off the aliens. However, the following elements feel like dead-ends:
  - Fighting off the aliens is fun for a bit, but without some pushback to letting them attack or some clear benefit from destroying them, it quickly loses interest.
  - Organizing the nodes is fun, but once you realize that all it gets you is a bit easier of a time in combat (since you can get the credits faster by just exploiting it), it loses value.
  - Finding a good spot to seal is an interesting problem, but frustrating when you fail and aren't sure if it was because you missed something or just because this particular level has some quirk.
  - Finding ways to close the loop on these mechanics and let them feed into each other or themselves to improve future play would dramatically increase the value to the player.
- Some indication of global progress and/or leaderboard rank would help motivate players to improve their own score.
  - This also might be true for solutions to individual levels, if there's some way to optimize them, and/or for combat-related feats.
  - Achievements or some form of high score, both globally and personally, would help players compare their success to what is possible and gain some value from interacting with what others are achieving.

Appendix G.   CSFV Marketing and Promotional Materials

Usability Testing

Goal: First Make Games FUN!

- Work to create games **anyone can play** with familiar mechanics and environments. **Lower the learning curve** with common themes, simple commands and easy interfaces.

- Long tutorials don't always work to teach players and can lead to **acquisition and retention problems.** Show gameplay in **short bursts**, then allow players to play "real" levels. Teach new mechanics as needed.
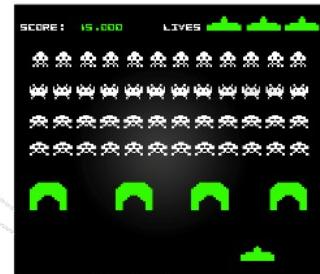
Share Your Insights and Learn from Other Teams

- The Next Steps reports we've seen so far have identified a number of **important usability issues** and have **shared several valuable solutions.** Consider those ideas and **how they can be applied to your game.**

2015 Strategic Marketing Plan Updates

A Major issue for players is they don't see the consequences of their play—even negative consequences are motivators. [3]

Think about core pillars of game design:

1. Consequences of gameplay actions are clear rewards or negative consequences.
2. Belonging/teamwork
3. Novelty/surprise
4. Mastery—being able to improve and master

Consider these pillars and similar concepts in next steps (usability testing review) documents.

Strategy:

How is Design Club going? How much fun are the games? How easy are they to get into for a new player? How about obstacles for new players—long tutorials, long learning curves, frustration factors, etc.?

Acquisition and Retention—Can players get into "real" gameplay quickly, or are they stuck in long tutorials? Are all game mechanics being taught at the start of games, or when they are needed?

Pillars of game design—Consequences of actions, negative or positive, clear rewards or negative consequences. Make sure players know if what they did was bad or good.

Sense of belonging—Is there a way to integrate teamwork/social? Working toward a collective goal is implied—CSFV. Can we make this a key component of each gameplay session?

Novelty/Surprise—What's new and interesting as players play?

Mastery—Can players improve as they play? How do they know they are mastering the game?

Key Message:
Data Security is Getting More Important All the Time

Key Call to Action:
Play Games to Help Make Data More Secure

- Due to our communication constraints, we can't create traditional mission statements or brand differentiators. We need to **communicate our key messaging and call to action** in our **overall PR and social media marketing**. We need to **explain how players contribute** to science and software security, i.e., *what this project does*.

Some Message Elements

- *Infographics*—Showing how a **game performs CSFV**.

- *Text-based*—Blog posts and other articles **describing how the project works** and how the **development process has evolved**.

- *Hints & Tips*—Short blurbs about each game that **tell how they work** and **contribute to the project**. Useful for in-game load screens, social media posts, community postings, etc.
  "Did you know Monster Proof solves 23 equations every time you level up?"
  "Dynamo is calculating proofs as you make choices from the Analyzer Tools."
  "Paradox is verifying software as you select multiple nodes and run the solver."

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Strategy:

Infographics—Show how games perform CSFV. Are games in a place to create infographics? Are assets available? Is there bandwidth to provide assets and mockups with text? Infographics can be introduced in newsletters and other social and press to provide info and create buzz.

Blog Posts—What are you doing that's different? Can repurpose scientific paper stuff for blog posts, blurbs, short articles, captions, etc. and other material for Citizen Science page?

Hints & Tips— Created from tutorials and rolled out at launches.

PR

Press Kit—Materials for Phase 2 Games

- High Res Logo
- High Res Screenshots (minimum 5)
- In-Game High Res Icons, Characters, etc.
- In-Game Fonts
- In-Game Sounds & Music
- Teaser Video
- Launch Press Release—*Written by In-House PR if Possible*
- Dev Team Updated Contact Info & Titles
- Updated Press Contact
- Press Kit Will Be Posted Online

Teaser Ad Campaign Before Launch

- Series of ads for Google ad network and social media to create **pre-launch buzz about Phase 2**. Ads **show the work already done by the CSFV program** using a comparison method. (A graphical representation of the amount of data Verigames gameplay has analyzed.) *We first need DARPA permission to release this data.*

- The tagline at the bottom of each ad will be something like, *"Verigames Phase 2 Games Are Poised to Achieve Even More! Get Ready to Play!"*

PLAY TO CURE™
GENES IN SPACE

IN ONE MONTH CITIZEN SCIENTISTS' HAVE ANALYSED AROUND **40** MILES OF DNA DATA

THIS IS THE LENGTH OF **540** FOOTBALL PITCHES

AND AROUND **170** TIMES THE HEIGHT OF THE EMPIRE STATE BUILDING

DATA ANALYSED WOULD HAVE TAKEN A SCIENTIST APPROXIMATELY **6 MONTHS** TO ANALYSE THAT AMOUNT BY EYE
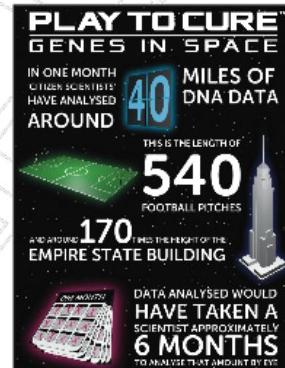
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Strategy:

Teaser Material—Concept art, placeholder art as well as game design comps and mockups are all good as teaser material and social media marketing. Need to be submitted to PAO so can be used.

Ad Campaign Above is a Suggestion—Needs PAO approval. Is it a good idea in terms of comparison—that is, what kinds of comparisons can be made of CSFV progress with real-world items? Verigames has analyzed X amount of data, etc? What kind of data relates to what game?

Generate Excitement on Social Media and Press about Phase 2—Need all dates to create press calendar. Need to create press calendar that takes PAO approval times into account.

Utilize All TA1 Press Departments As Possible—Get press releases written and disseminated by SRI, UCSC, BBN/Raytheon, Center for Game Science, etc. as much as possible. Work with these groups to do all possible follow up with existing press contacts for coverage. Last time they made promises they did not keep. How can we get them to follow through?

Press Release Push at Launch

- *Start with traditional PR*—Press releases sent out to as **many relevant outlets as possible** with **follow-ups to encourage coverage.**

- *Support with ongoing social media marketing*—Posts of in-game content, blogs, media coverage and relevant related content **across social media.**

Advertising—Google Networks and Social Media Boosts

- Currently gathering advertising intelligence using small ad buys (October through April). Small buys of Adwords, static and animated banners, seeing what works best to **improve our key conversion metric—new players.**

- Also watching social media traffic, site traffic, community engagement and new registrations as additional information on **what advertising is working in what markets.**

- Will do bigger **Phase 2 ad buys at launch** using gathered advertising intelligence.

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Strategy:

Asking all companies with in-house PR to write and send their own releases to their own press contacts for maximum coverage for investment. We will support others as needed, ensuring no PR overlap.

Need high quality art, logos, taglines and other game info to create ads that work.

Work on Ads for Google Network—Get that going with TopCoder/Appirio. Games that have relevant assets, start creating banners (animated up to 150K at sizes we tested).

Check In on Ad Budget, Method of Payment, Etc. Based on 2014 Tests—Never received relevant social media traffic, site traffic, community engagement analytics. Ask for that material from Appirio.

New verigames.com Citizen Science Webpage

Will contain modules with several forms of **CSFV scientific information** to accommodate different ways people take in information and/or personal preference.

We want users to be able to **find the info they want** in a form they can absorb. If users want to go deeper—the **resources are available.**

- Blog Posts
- Images with Captions
- Blurbs
- Media Articles
- Infographics
- Scholarly Articles
- Bibliography
- Video & Podcasts

2015 Strategic Marketing Plan Updates

Strategy:

Citizen Science Web Page—What's the status?! Need to know ASAP. Citizen Science is vital to phase 2 marketing strategy! Working with TopCoder web design to best integrate header into overall site so it's easily accessible throughout without a "pasted-on" look and feel. Working to reduce bounce rate and increase key conversion metric—game players—by providing info people are looking for—without the clicking around heatmaps we saw before. May use A/B testing to optimize best methodology. Can do usability testing on website to obtain user input.

Verigames.com—What's up with the phase 2 website? Need to get an update from Appirio ASAP. Excellent usability on verigames.com and optimized implementation of Citizen Science section are vital to phase 2 marketing strategy. Very concerned that design/implementation holdups will cause problems executing marketing strategy and/or will cause the same major problems of phase 1—will make Verigames not look like a going concern. In phase 1, the website was "Coming Soon" for a year! My direction took months to be implemented and 75% of was never implemented with no explanation. If that happens in phase 2, users will again come to a website that looks like it is not happening, which will again lead to a significant volume of bounces before players even try games. Plus, press outlets will not give us a second chance for coverage if we can't get the site going 18 months later. Concerned about Wiki—most recent content nearly 500 days old. . . "About Us," "FAQ" is from 2013 and is still referencing TopCoder as legal entity (prime contractor). Forums and game comments are all many months old. . .

- *Introduce community integration into games as rewards*—**Naming rights** of levels and other in-game artifacts.

- Add **friendly competitions** and other **social in-game interactions**.

- **Integrate pop-ups** that come up after a few moves, every level, every few minutes, etc. that **encourage guest players to register** so they can become part of the community.

- The verigames.com **Forums section has been revamped** so it's better organized, easier to use and more attractive, making it **more useful** for community members and **more welcoming** to new players.

- *Encourage new people to become part of the community through direct interaction between players and developers*—Encourage players to post questions, host live chats with devs, play live game demos, tournaments, etc.

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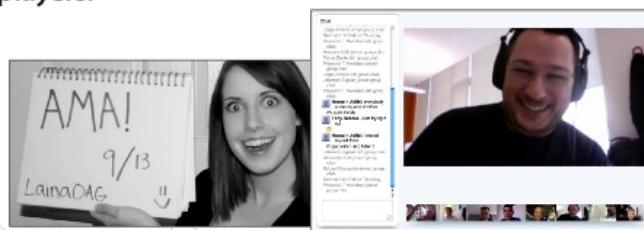
2015 Strategic Marketing Plan Updates

Strategy:

There has been a lot of talk about integrating community gameplay mechanics options among game Design Club, other game design conversations and past PI meetings. It's time to begin real integration of community mechanics across and between games. I would like to see community features tested in our next usability testing session and potentially A/B testing on the verigames.com website using analytics.

Developer Interaction with Player Community—Plan on direct developer interaction with player community at least once a month starting at launch. Can be AMAs, tournaments, chats, etc.

Overall Community in Games—What social integration is available in your game? Rewards? Competition? Registration encouragement? Interaction between players and developers? What's your preference? What's best for the title? Can you partner with another game (or all the games?) to create group interaction among players to get players to try other games?

Retention Strategies

- *Player Bonuses*—In-game score or other **bonus on a timer** that **lasts longer than the average play session.** Players **come back for the bonus.**

- *Daily Bonuses*—**Players come back to the game** to get the bonus.

- Implement **in-game progress bars** that **indicate player progress in CSFV.**

- Create **infographics about each game's gameplay mechanics** (directed by development teams, created by TopCoder/Appirio).

- **Create a video walk-through/tutorial** for each game **before launch.** Tutorials should be **short and simple.** It's better to have more than one video—perhaps illustrating a **particular gameplay mechanic or section of the UI**—instead of a single long tutorial video. For wide-ranging tutorial examples, check Twitch and YouTube.

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2015 Strategic Marketing Plan Updates

Key motivators that act as passive "consequences" of player non-actions have been proven to work across casual, social, mobile and free-to-play.

Offer multiple game learning strategies. Folks refuse to read and are saying tutorials are too long in usability tests. Yet, they need to learn the games somehow. Allow them to pick up and play—and go back and learn more later once they're interested and invested in the game with bonus points.

Strategy:

Retention—Daily bonuses? Times bonuses? CSFV progress bars? Video walkthroughs?

Multiple Learning Strategies—Can pick up and play, earn bonuses and then learn key mechanics once invested.

- *Notifications*—Non-annoying messages sent through social media. **Provide science info about CSFV or** other relevant science info of the day. *"Verigames congratulates the Rosetta Mission on its historic achievement!"* (with embedded link for users' convenience).

- A lot of players are in fields similar to CSFV. **Target those fields** by providing **information of interest** to them.

- **People in the field sometimes don't want "fluffy" games.** (The Xylem team learned some of their players just wanted the math and wanted to get rid of the island story of the game.) **Create settings** that'll allow players to turn off the "fluffy stuff."

- The default should be **games that are accessible to the widest possible audience.** **Provide pop-ups** informing players of available settings.

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Settings can also be a pre-cursor to Mechanical Turk games (turn off everything for MT version?). Can make game simpler without "fluff" for serious types.

Notifications that provide information that's useful/interesting can remind players of the games while actually providing content of use. Must be careful not to endorse according to DARPA guidelines—scientific, educational, historic, okay. Product, brand, celebrity, etc., not okay.

Strategy:

Retention—Social media messages about science in general and CSFV, targeting similar science fields.

Appendix H.   Verigames Contest Rules

Within the DARPA Crowd Sourced Formal Verification (CSFV) Program, the Defense Advanced Research Projects Agency (DARPA), Air Force Research Laboratory (AFRL), Charles River Analytics Inc., and TopCoder, Inc. will be holding a contest to reward high-scoring players across each of the five games with community events and prizes. During the next four weeks, we will track game scores across all players in the community, and across all games. For each game, we will provide rewards to the top 5 scorers as outlined below:

- **First Prize**: The top scorer from each game will be invited to participate in a live web conference with game developers and DARPA representatives from the CSFV program. This conference will start with a 30-minute presentation from DARPA describing the goals and the approach of the program, followed by a 30-minute presentation from the game developers describing the approach of their games. Finally, it will end with a 30-minute chat session in which developers will answer questions from the winners. Winners of the first prize will gain a special tag to their account identifying them as game gurus, linked to any of their posts on the forum and their participation in live chat features for each of the games.

- **Second Prize**: The second and third scorer from each game will have access to a recorded segment of the web conference described above, focusing on the first hour of the session (the 30 minute DARPA presentation and the 30-minute game developer presentation). Winners of the second prize will also have access to the third prize as well. Winners of the second prize will gain a special tag to their account identifying them as game experts, linked to any of their posts on the forum and their participation in live chat features for each of the games.

- **Third Prize**: The fourth and fifth scorer from each game will gain an honorable mention tag to their account identifying them as strong contributors, linked to any of their posts on the forum and their participation in live chat features for each of the games.

Contest rules and details:

- To participate, you must have a tracked account on Verigames.com; anonymous players will not be eligible for any rewards.
- Winners will be responsible for their own network fees to participate in the web conference and/or to access videos of that conference; DARPA, Verigames, TopCoder, and Charles River Analytics bear no responsibility to provide or maintain connections to support participation.
- The contest will be conducted July 13, 2015 through August 14, 2015. Only scoring accrued during that period will be considered as part of the performance assessment entering into the contest.
- The date of the community event is to be determined, but will occur within 4 weeks after the end of the contest.
- Questions for the development team and DARPA must be submitted and approved at least one week prior to the targeted chat.
- All prizes are considered to have no monetary value. Prizes are intended for the community members who win, and will not be transferable to other community members or non-community members.
- The prizes listed above are considered to have no monetary value; winners will receive no monetary rewards based on this contest.

- You must be 18 years or older to win. Void where prohibited.

Distribution Statement A: Approved for public release; distribution unlimited

Appendix I. Usability Study: Dynamakr

I.1 Objectives

These games are made to be somewhat complex, as the movements and objectives help to solve complex mathematical problems. The key business objectives are to review:

1. Tutorial effectiveness in onboarding
2. Gameplay mechanics and impacts on retention
3. Guidance and direction support
4. Engaging and lasting gameplay

I.2 Demographics

The population consisted of 10 users who were reasonably distributed across the United States. Most subjects were 25-44 years old, with one in the 18-24 range and one in the 45-64 range. The population was relatively evenly split in gender (6 female, 4 male). All subjects had a household income between $30,000 and $99,000.

I.3 Behavior Metrics
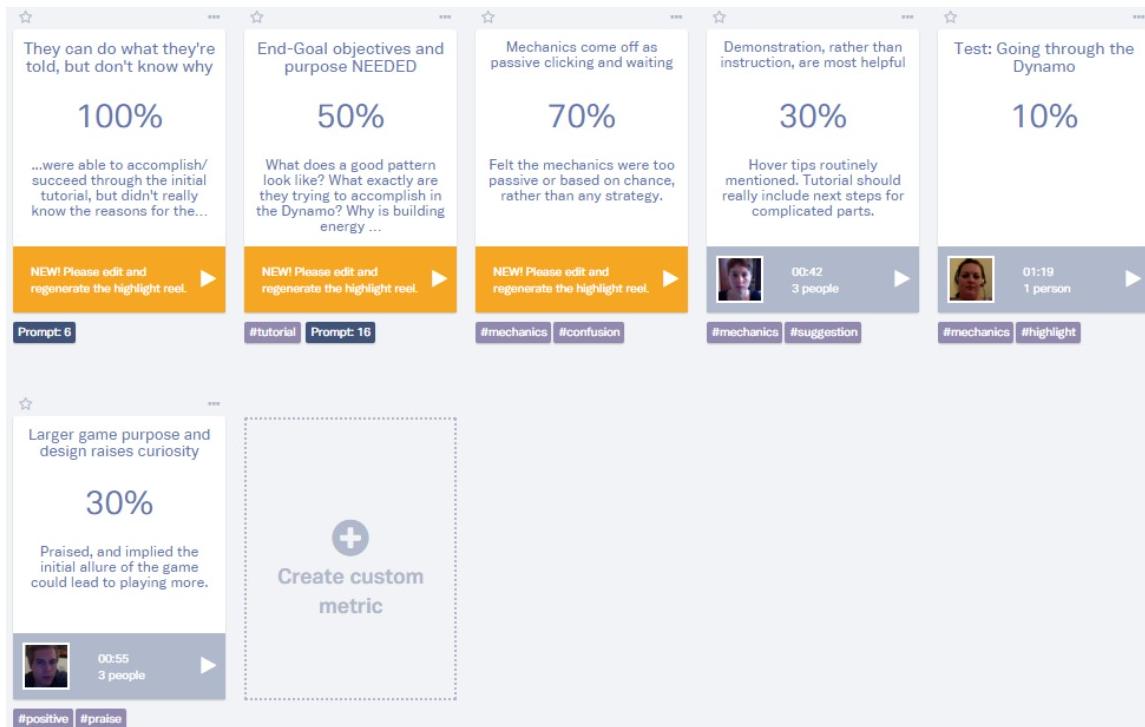
I.4 Key Findings

Key findings included the following:

1. Initial intro and design allures people to potential of engaging gameplay. Maintain sound effects and galactic scale.
2. High success with building patterns, some miss energy building requirement.
3. What makes a pattern better than others? Why would you load up on the right, but not on the left?
4. Unless paying close attention, it is very easy to miss how pattern building relates to what the Dynamo experience will be like. This is pivotal. Should players be utilizing strategy when building patterns as a way to impact the Dynamo shoot-out? If so, communicate earlier.

5. Make certain that Go Dynamo! and Continue buttons are large and noticeable, some missed them initially which caused delays. Potentially, just remove any need to click to the next space, as long as there is some transition demo to introduce the Dynamo and levels.

6. Majority suggest leveraging more tooltips and hover instructions when doing certain interactions, rather than large chunk of text before and after parts of the tutorial.

Appendix J.   Usability Study: Binary Fission

J.1   Objectives

These games are made to be somewhat complex, as the movements and objectives help to solve complex mathematical problems. The key business objectives are to review:

1. Tutorial effectiveness in onboarding
2. Gameplay mechanics and impacts on retention
3. Guidance and direction support
4. Engaging and lasting gameplay

J.2   Demographics

The population consisted of 11 users who were reasonably distributed across the United States. Most subjects were 25-44 years old, with some in the 18-24 range, and one in the 45+ range. The population was relatively evenly split between males and females. Most subjects had a household income between $40,000 and $99,000, with several in lower income brackets.

J.3   Behavior Metrics
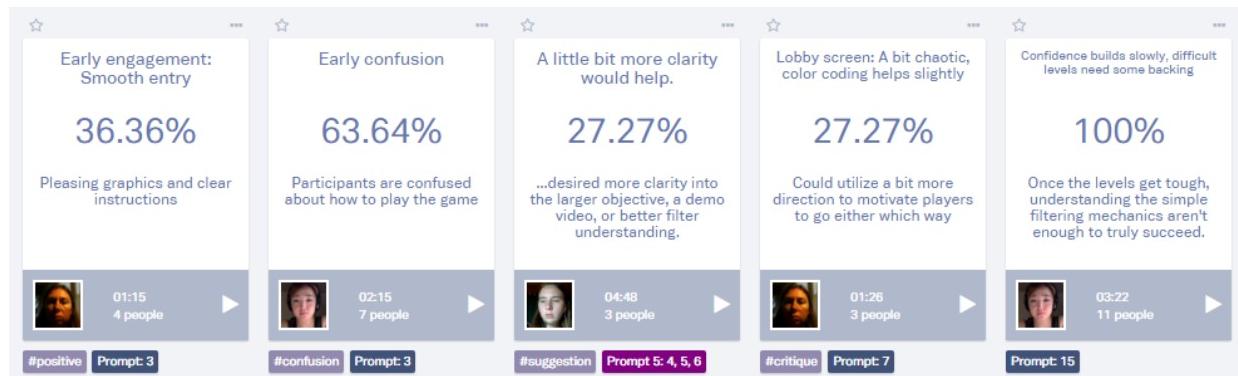
J.4   Key Findings

Key findings included the following:

1. Simplicity of the game leads to fairly successful ramp-up, but a video demonstration or light back-story would increase engagement
2. Minimal feedback during filter splitting leads to doubt. Utilize sound or color feedback to increase awareness of success or failure
3. Once the levels get tough, understanding the mechanics builds confidence, but ~50% of the participants wanted something more to work towards. Some assumed that the correct filter path created a larger pattern or form, but this was not ever confirmed.
4. Design mostly pleases. Largest gap in elements is how score is calculated.
5. Increase the competitive nature through friend referral and 1v1 competition of the same levels.
6. Most participants could have used a slightly longer transition to harder levels while mechanics are given feedback and the score is explained.

# Appendix K.   Usability Study: Monsterproof

K.1   Objectives

These games are made to be somewhat complex, as the movements and objectives help to solve complex mathematical problems. The key business objectives are to review:

1. Tutorial effectiveness in onboarding
2. Gameplay mechanics and impacts on retention
3. Guidance and direction support
4. Engaging and lasting gameplay

K.2   Demographics

The population consisted of 10 users who were reasonably distributed across the United States. Most subjects were 25-44 years old, with one in the 18-24 range and one in the 45-64 range. The population was mostly female (7 participants). Most subjects had a household income between $30,000 and $79,000, with two in lower income brackets, and one in a higher bracket, and one unspecified.

K.3   Behavior Metrics
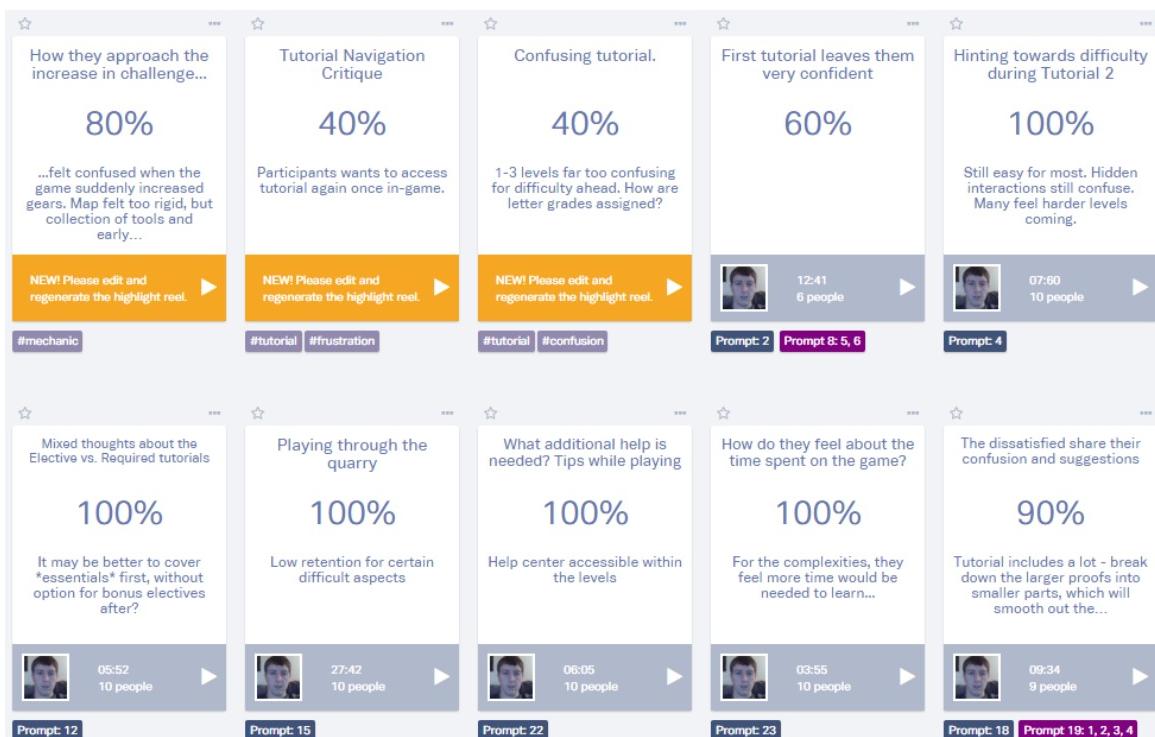
K.4   Key Findings

Key findings included the following:

1. Difference between first proof and later equations scales rapidly with little opportunity for confidence building.
2. Tutorials add up for too much length – requires a lot of memory retention.
3. Very important to give feedback when proper balance of monsters initiated – do not wait for player to test equation.

4. Map felt too rigid for some, but collection of tools and early challenge excited many.

5. Utilize the difficulty of tutorials 2-3 for a bit longer. Very easy levels over and over to build confidence, gain some tools, and introduce the other game mechanics while players do not lose faith.

Appendix L.   Usability Study: Paradox

L.1   Objectives

These games are made to be somewhat complex, as the movements and objectives help to solve complex mathematical problems. The key business objectives are to review:

1. Tutorial effectiveness in onboarding
2. Gameplay mechanics and impacts on retention
3. Guidance and direction support
4. Engaging and lasting gameplay

L.2   Demographics

The population consisted of 10 users who were reasonably distributed across the United States. Most subjects were 25-44 years old, with two in the 18-24 range. The population was mostly female (7 participants). Most subjects had a household income between $40,000 and $99,000, with two in lower income brackets, and one in a higher bracket.

L.3   Behavior Metrics
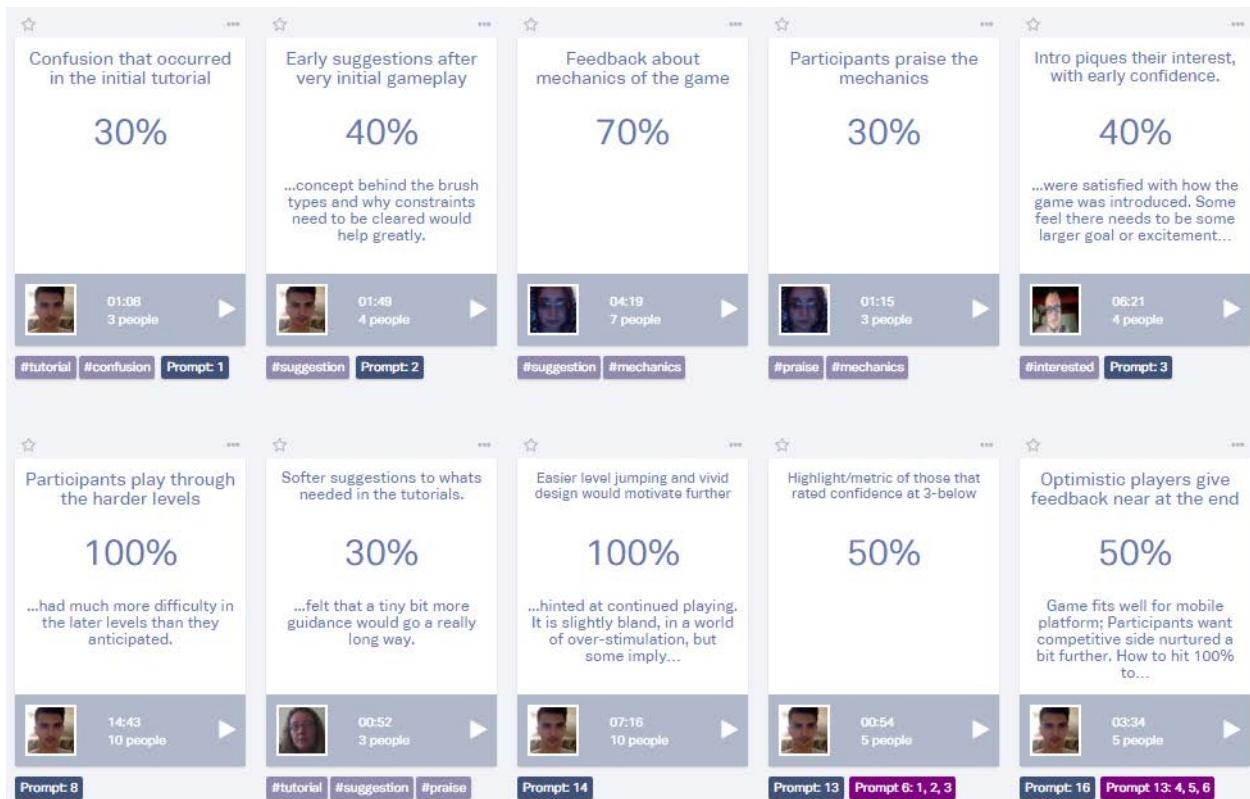
L.4   Key Findings

Key findings include the following:

1. Tutorial instructions too distant from paintbrush actions and paintbrush type; difficult to recall strengths of paintbrushes.
2. When new paintbrushes are introduced, animation demo of how they differ would help greatly. Along with the ability to constantly be reminded via hover or name of brush next to brush image.

3. Design palette slightly soothing, a bit polarizing: too dull for some. But for several, it achieves a nice tone.

4. Scale and scope of map size still a bit jarring when later levels are played. Playing a map incrementally, starting from further zoomed in on the difficult areas, may lead to a better engagement curve.

# Appendix M.   Usability Study: Ghost Map – Hyperspace

M.1   Objectives

These games are made to be somewhat complex, as the movements and objectives help to solve complex mathematical problems. The key business objectives are to review:

1. Tutorial effectiveness in onboarding
2. Gameplay mechanics and impacts on retention
3. Guidance and direction support
4. Engaging and lasting gameplay

M.2   Demographics

The population consisted of 10 users who were mostly distributed in the Eastern United States. Most subjects were 25-44 years old, with two in the 45-64 range. The population was mostly male (7 participants). Most subjects had a household income between $40,000 and $99,000, with two in lower income brackets.

M.3   Behavior Metrics
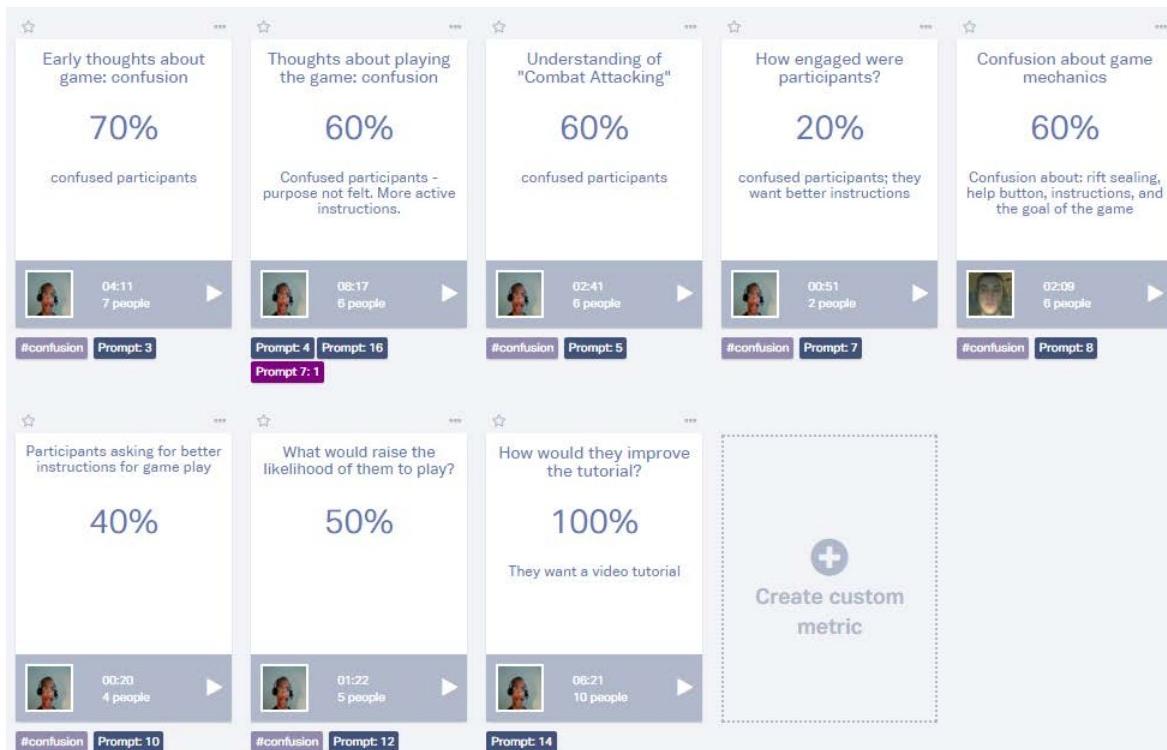
M.4   Key Findings

Key findings included the following:

1. Intro voiceover should contain a video of some sort to excite and engage. Voiceover easy to click through and miss.
2. Greatest confusion is around Rift Sealing. Why must they use the bottom right sliders, rather than interacting in the primary map area?
3. Participants did not seem to grasp the connection between Combat and Rift sealing. How does a good seal relate to killing the bugs and locking?

4. Locking a map in and of itself is not made entirely clear. Participants achieve this, but is it just to keep the map clean? Or serve a larger purpose?

5. Feedback for bug health, along with health vials on the left side of the game, not given clear enough feedback/values.